



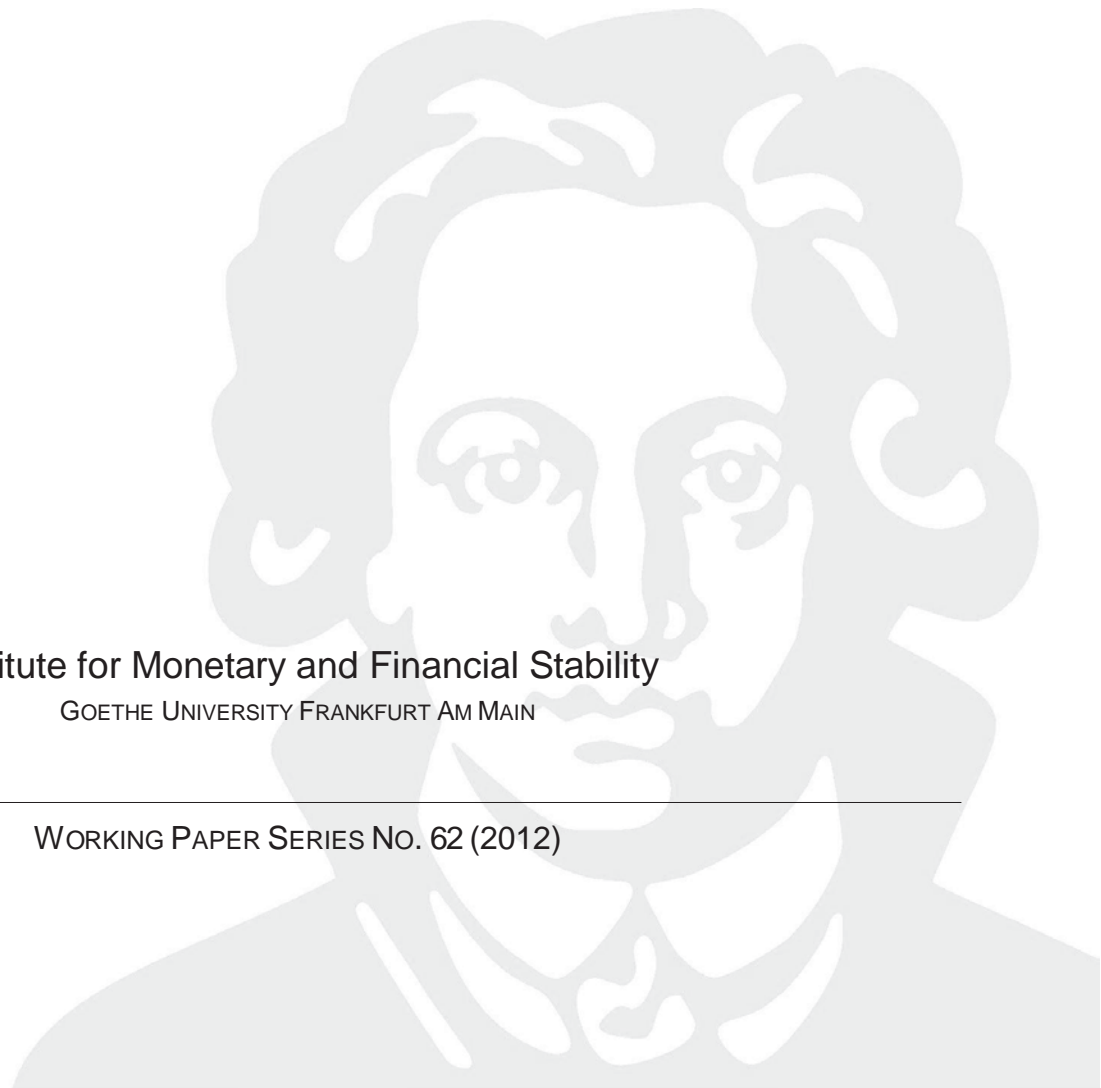
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## Forecasting and Policy Making

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WORKING PAPER SERIES No. 62 (2012)



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# Forecasting and Policy Making\*

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October 3, 2012

*Keywords:* Forecasting, monetary policy, fiscal policy, DSGE models, conditional forecasts, policy rules, expectations, business cycles, robust policy

*JEL-Codes:* A33, C53, E17, E27, E31, E32, E37, E52, E58, E61, E62, E66

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\*Chapter prepared for the forthcoming Handbook of Economic Forecasting, Vol 2, North Holland Publishers, edited by Graham Elliott and Allan Timmermann. Helpful comments by Allan Timmermann, Graham Elliott, Marta Banbura, Todd Clark, Kai Christoffel, William Gavin, Lutz Kilian, Mike Wickens, Jonathan Wright, participants at the Handbook of Economic Forecasting Conference at the Federal Reserve Bank of St. Louis and the Society for Computational Economics Conference 2012 in Prague and two anonymous referees are gratefully appreciated. All remaining errors are our own. Wieland acknowledges research assistance support from the German Science Foundation, DFG Grant No. WI 2260/1-1 AOBJ 584949. Wolters thanks the Stanford Institute for Economic Policy Research (SIEPR) where he was a visiting scholar while part of this research was conducted.

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# 1 Introduction

*Gouverner c'est prévoir* (Emile de Girardin, 1806-1881)

*Implicit in any monetary policy action or inaction is an expectation of how the future will unfold, that is, a forecast.* (Greenspan, 1994, p. 241)

Forecasts play an important role in economic policy making, because the economic consequences of a policy decision made today only unfold over time and the new policy is typically intended to remain in place for some period. They are unavoidably fraught with uncertainty due to imperfect understanding and observation of the mechanisms and forces determining economic outcomes. Formal treatments of the proper use of forecasts in policy making go back to Theil (1958) building on Tinbergen (1952)'s theory of economic policy. Theil suggested that (i) the policy authorities have to predict impending changes in the economic environment; (ii) then they have to prepare forecasts of the effect of adjustments in the policy instrument, and (iii) based on these forecasts a plan of policy actions must be developed. The following practical example is still relevant today: *"In the case of employment policy, it is necessary to obtain some idea as to the factors controlling next year's or next quarter's employment level. If this leads to a predicted employment which is considered too low, the policy-maker will try to find measures in order to increase the level; and then it is necessary to predict the effectiveness of alternative measures, i.e., of the reaction of variables which are not controlled to changes in controlled variables. This leads to a plan of actions, which may be followed or abandoned in the light of subsequent events."* (Theil, 1958, p. 3).

Of course, forecasts can be usefully employed in many areas of economic policy. In this handbook chapter we focus on the forecasting models and methods used in the context of monetary and fiscal policies for assessing their consequences for aggregate economic fluctuations. Central banks have long been concerned with estimating the transmission of changes in policy instruments such as the short-term nominal interest rate to target variables such as the rates of inflation and output growth. Their decisions are typically related to forecasts and adjusted frequently in response to new data, which induce forecast revisions. Fiscal policy has many tasks. Policy makers regularly need to decide on the size of the government budget, how to finance and how to spend it. They have multiple instruments at their disposal. Furthermore, budgetary forecasts are influenced in turn by economic developments. Occasionally, fiscal authorities also consider major reforms in taxation, debt or spending policies that require forward-looking impact assessments.

The role of forecasts in policy making is a very broad topic. Space requirements force us to omit many relevant and interesting theories, techniques and applications. Wherever possible we refer to other sources for topics that are only treated in a cursory fashion in this chapter. Instead, we focus on a few specific and related questions. Section 2 begins with a recent practical example concerning the role of forecasts in policy making, namely prediction of the GDP impact of 2009 fiscal stimulus legislation in the United States. Then it presents a simple theoretical framework for linking forecasts with policy preferences and policy decisions. This framework applies the principles of Tinbergen and

Theil's theory of forecasting and policy making to central bank interest rate decisions for macroeconomic stabilization purposes. Alternatively, a modified version of this framework with a fiscal sector could be used to analyze the role of fiscal policy in macroeconomic stabilization.

Section 3 reviews examples of forecasts produced at fiscal and monetary authorities. Particular emphasis is given to forecasts produced at the Federal Reserve and the European Central Bank because they are used again in subsequent sections. In section 4 we address the question whether policy makers adjust their decisions directly in response to economic forecasts. Answering this question requires an empirical investigation. Of course, it is easiest to search for such a link in an environment in which decision makers are exposed to a particular forecast on a regular basis and shortly thereafter make a policy decision that becomes public right away. Thus, it is most easily tested in the context of central bank interest rate policy. We show that interest rate setting by the Federal Reserve and the European Central Bank is quite well explained by a response to forecasts.

Section 5 then reviews how to compute forecasts that account for the interaction with policy decisions. Thus, it focuses on the use of structural macroeconomic models for forecasting. These models incorporate explicit assumptions regarding the decision making of monetary and fiscal policy makers concerning variables such as government spending, taxes, transfers, central bank interest rates and central bank money. Furthermore, they provide characterizations of the decision making and expectations formation of households and firms that indicate how they will change their behavior in response to systematic changes in policy maker decisions. We review models used at central banks, fiscal authorities and international institutions. Then we construct forecasts from a small projection model used at the International Monetary Fund and from a medium-size DSGE model that is similar to models now widely available to staff at monetary and fiscal authorities. Of specific interest to us are methods used for conditioning forecasts on particular planned policy initiatives. An application deals with projecting the GDP impact of US fiscal stimulus legislation discussed in the practical example of section 2. The section concludes with an assessment of forecast accuracy and a comparison of model and expert forecasts. Given the observed heterogeneity of forecasts, the chapter closes with a normative analysis of the performance and robustness of forecast-based policy rules under model uncertainty in section 6. Section 7 concludes.

## **2 The role of forecasts in policy making: A practical example and a theoretical framework**

### **2.1 A practical example: Forecasts in U.S. fiscal policy**

To illustrate the interaction of forecasts and policy decisions, we consider the following example from the United States. On February 17, 2009, U.S. Congress enacted the American Recovery and Reinvestment Act (ARRA). It was a very unusual policy measure involving spending increases, transfers and tax reductions on the scale of 787 billion U.S. dollars that were meant to stimulate economic activity following the global financial crisis. On January 7, 2009, the Congressional Budget Office had

published its regular Budget and Economic Outlook for the next 10 years. Its forecast for the remainder of 2009 implied a drop in real GDP of 2.2 percent followed by an increase of 1.5 percent in 2010. As usual, the CBO's near-term outlook was based on the assumption that "*current laws and policies governing federal spending and taxes do not change*" and therefore did "*not include the effects of a possible fiscal stimulus package*".<sup>1</sup> On January 9, President Obama's advisers Christina Romer and Jared Bernstein circulated a report on the impact of the American Recovery and Reinvestment Plan predicting that such a plan could raise GDP by 3.6 percent above the baseline forecast within 2 years (Romer and Bernstein, 2009). Their calculations were based on measures of government spending and tax multipliers obtained from private sector forecasters and the Federal Reserve. Over the course of January and early February 2009, CBO prepared several budgetary and economic impact forecasts of the stimulus legislation debated and eventually passed in the House of Representatives and the Senate in response to requests by members of U.S. Congress. On March 20, 2009 CBO released an update of its budget and economic outlook taking into account the policy changes implied by the ARRA as well as new incoming economic data suggesting a more negative economic outlook than the data available for the January forecast.<sup>2</sup> On this basis, they predicted a steeper decline of real GDP in 2009 of -3.0 percent followed by an increase of 2.9 percent in 2010.

This example shows that economic policy is not only based on macroeconomic forecasts, but that the path of policy itself has a direct effect on projections of macroeconomic aggregates. Thus, forecasters need to base their predictions on specific assumptions regarding future policy. For example, professional forecasters and macroeconomists often use a particular future path for fiscal policy that they consider most likely to occur or an estimated feedback rule that accounts for the response of future policy to projected future economic conditions. Forecasters employed by policy institutions typically also consider forecasts that are conditioned on unchanged policy as in the case of the CBO outlook. While such forecasts do not represent their best possible prediction of the future course of events, they are often used as a benchmark for the policy debate that helps set up desirable policy changes. Another important issue concerns the choice of economic model on which the forecast is to be conditioned. With regard to the ARRA, for example, a study by Cogan et al. (2010) using state-of-the-art New Keynesian models estimated much smaller multipliers than the models in Romer and Bernstein and predicted only about 1/6 of the GDP impact.<sup>3</sup>

## **2.2 A simple framework for modeling the interaction of forecasts and policy decisions**

In his formal treatment of economic policy, Tinbergen (1952) describes economic policy as the maximization of a collective ophelimity function by the government. This function contains a number of variables that the policy maker wants to influence but that are not directly under her control. These variables are called *targets*. Policy is implemented by manipulating variables that may be directly

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<sup>1</sup>See Congressional Budget Office, The Budget and Economic Outlook: Fiscal Years 2009 to 2019, January 2009.

<sup>2</sup>See Congressional Budget Office, A Preliminary Analysis of the President's Budget and an Update of CBO's Budget and Economic Outlook, March 20, 2009.

<sup>3</sup>A first working paper version was circulated shortly after the bill was passed in February.

controlled by the policy maker—so-called control or instrument variables. Tinbergen (1952) differentiates between quantitative and qualitative policy changes. Qualitative changes imply a change in the economic structure. Examples are the dissolution of a monopoly, the introduction of a customs union or a monetary union. Thus, qualitative policy involves choosing from a finite number of policy alternatives. Quantitative policy changes are defined as adjusting certain policy parameters or instruments such as taxes, government expenditures or interest rates to achieve policy goals within a given economic structure. Conveniently, Tinbergen (1952) lists the following steps for the proper conduct of economic policy:

- (i) choose a collective preference indicator;
- (ii) deduce targets for economic policy from this indicator;
- (iii) choose adequate instruments for achieving the targets;
- (iv) determine quantitative values of the instrument variables;
- (v) and formulate the connection between the targets and the instruments and the structure of the economy.

With regard to forecasts, Theil (1958, p.3) stresses that

*”A realistic analysis of the relationship between forecasts and policy must be based on the assumption of several variables controlled and not controlled by the policy-maker, of their interrelationships, (and) of the policy-maker’s preferences which serve to formalize the optimality criterion” .*

In the following, we review central bank interest rate policy using Tinbergen’s nomenclature and present a simple framework for linking forecasts with policy preferences and policy decisions aimed at controlling inflation and stabilizing economic fluctuations. Alternatively, a modified version of this framework with a fiscal sector could be used to analyze the role of fiscal policy in macroeconomic stabilization.

### **A simple model linking forecasts and interest rate decisions: Policy objective and instrument**

Typically, central banks do not publish an explicit objective function regarding collective economic welfare nor do they claim to optimize such a function.<sup>4</sup> Rather, a small number of targets or even a single principal target is specified by law. For example, the U.S Federal Reserve Act asks the U.S. central bank *”to promote effectively the goals of maximum employment, stable prices and moderate long-term interest rates”*. The Fed itself clarifies that stable prices in the long-run are a pre-condition for the other two goals, while acknowledging a short-run tradeoff between inflation and employment stabilization.<sup>5</sup> As to the euro area, the Maastricht treaty expresses a hierarchy of targets.

<sup>4</sup>An exception is the procedure of the central bank of Norway. Objective functions that represent the bank’s mandate and the board’s policy preferences and the model used to produce forecasts and guide monetary policy are public and discussed in some in detail for example in Alstadheim et al. (2010).

<sup>5</sup>See *”The Federal Reserve System: Purposes and Functions”*, [www.federalreserve.gov](http://www.federalreserve.gov).



”The primary objective of the ESCB shall be to maintain price stability” and ” without prejudice to the objective of price stability, the ESCB shall support the general economic policies in the community”, which is explained further as a high level of employment and sustainable and non-inflationary growth. Many other central banks are tasked with a primary responsibility for price stability and publish a numerical target for the rate of inflation. According to Bernanke et al. (1999) ” inflation targeting is a framework for monetary policy characterized by the public announcement of official quantitative targets (or target ranges) over one or more time horizons, and by explicit acknowledgment that low, stable inflation is monetary policy’s primary long-run goal.”<sup>6</sup>

Research and technical policy analysis require a mathematical specification of central bank objectives in order to evaluate a particular policy. There is a long tradition of using *loss functions* that penalize squared deviations of the target variables from a desired value. For example, price stability could be measured with regard to squared deviations of the price level from a target value or target path. Inflation targeting, instead, may be evaluated in terms of inflation deviations from target. Other variables, such as output or employment deviations from natural rates or the variability of the change of interest rates are also often included in such loss functions. The following example captures the dual objective of the Federal Reserve, though with output in place of employment:

$$L = E \left[ \sum_{j=0}^{\infty} \beta^j [(\pi_{t+j} - \pi^*)^2 + \lambda(y_{t+j} - y_{t+j}^*)^2] | I_t \right]. \quad (1)$$

$E$  denotes the expectations operator conditional on the policy maker’s information set  $I_t$  in period  $t$ .  $\pi_t$  is the inflation rate and  $\pi^*$  is the inflation target.<sup>7</sup>  $y_t$  denotes output, while  $y_t^*$  refers to the associated target. Central banks typically associate  $y_t^*$  with potential output,  $\bar{y}_t$ , which is the long-run level of output consistent with stable inflation. It is important to recognize that potential output is an unobservable variable and central banks would have to rely on imprecise estimates in pursuing such an objective (cf. Orphanides and van Norden, 2002). There are two preference parameters.  $\beta$  is a discount factor, ( $0 < \beta < 1$ ), while  $\lambda > 0$  indicates the weight assigned to output relative to inflation stabilization. Interestingly, this particular loss function also happens to approximate representative-household utility in a specific small-scale New-Keynesian model (see Woodford, 2003).<sup>8</sup> Arguably, it does not reflect very well the hierarchical nature of objectives—i.e. price stability first—that is enshrined in many central bank laws.

<sup>6</sup>The ECB differentiates itself from inflation-targeting central banks by means of its two-pillar strategy which involves a medium-term cross-check with monetary trends. Its numerical definition of price stability is an inflation rate below, but close to 2 percent.

<sup>7</sup>As to the Federal Reserve, Chairman Bernanke explained in 2009 that ”the longer-term projections of inflation may be interpreted [...] as the rate of inflation that FOMC participants see as most consistent with the dual mandate given to it by Congress – that is the rate of inflation that promotes maximum sustainable employment while also delivering reasonable price stability,” (Bernanke, 2009) As of January 2012 the FOMC specified its target publicly.

<sup>8</sup>A positive value of the inflation target is often justified as a means for minimizing the impact of the zero lower bound on nominal interest rates on policy effectiveness (Coenen and Wieland, 2004).

Turning to the main instrument of monetary policy, nowadays most central banks use a short-term interest rate such as the federal funds rate in the United States.<sup>9</sup> Following Taylor (1993) it has become quite common to characterize central bank policy as an *interest rate rule* that responds to recent outcomes (or nowcasts) of target variables such as inflation and the output gap:

$$i_t = \bar{r} + \pi^* + \phi_\pi(\pi_t - \pi^*) + \phi_y(y_t - y_t^*). \quad (2)$$

Here,  $\bar{r}$  refers to an equilibrium real interest rate, which together with the inflation target, sums to the equilibrium nominal rate.  $\phi_\pi$  and  $\phi_y$  constitute the central bank's response parameters. Using values of 2 percent for  $\bar{r}$  and  $\pi^*$ , 1.5 for  $\phi_\pi$  and 0.5 for  $\phi_y$ , Taylor (1993) showed that the implied interest rate path matches Federal Reserve policy from 1987 to 1992 very well. However, he had not estimated this relationship. Rather, these values of the response coefficients had delivered good stabilization performance in a variety of models used in a major model- and policy-comparison exercise (see Bryant et al. (1993)). Such performance evaluations follow Tinbergen's task list by using models of the relationship between policy instruments and targets (item (v)) to investigate the performance of interest rate rules (items (iii) and (iv)) with regard to a loss function that is specified in terms of target variables such as equation (1), (items (i) and (ii)). Specifically, these evaluations used the weighted average of the unconditional variance of inflation and the output gap, that is the limiting case of equation (1) without discounting.<sup>10</sup>

Of course, just as central banks have typically avoided committing to a particular loss function, they have also abstained from announcing a fixed interest rate rule. Nevertheless, inflation targeting central banks such as the Bank of Canada and the Bank of England have used Taylor-style rules with forecasts early on in order to operationalize inflation-forecast targeting in model-based evaluations and projections (cf. Haldane, 1995; Amano et al., 1998; Batini and Haldane, 1999). Such a *forecast-based interest-rate rule* can be defined analogously to equation (2):

$$i_t = \bar{r} + \pi^* + \phi_{\pi,h}(E[\pi_{t+h}|I_t] - \pi^*) + \phi_{y,k}(E[y_{t+k} - y_{t+k}^*|I_t]), \quad (3)$$

where the subscripts  $h$  and  $k$  denote the forecast horizons of inflation and output forecasts, respectively. The policy maker's target is included in the expectation, assuming that policymakers aim at potential output. Similarly, its current value in equation (2) has to be understood as a nowcast.

### The macroeconomic model

Item (v) on Tinbergen's list requires a particular *model* of the transmission of monetary policy to policy targets. As a simple example, we consider the following three-equation model in the spirit of

<sup>9</sup>We abstract from other instruments used when interest policy is inhibited by the zero-lower-bound as in the course of the recent recession. See Wieland (2010) for a review of earlier research on policy instruments at the zero-bound.

<sup>10</sup>See Taylor (1999) and Taylor and Wieland (2011) for similar studies.

Svensson (1997) and Orphanides and Wieland (2000b):

$$\pi_{t+1} = \pi_t + \kappa(y_t - \bar{y}_t) + \gamma z_{t+1} + \epsilon_{t+1} \quad (4)$$

$$y_{t+1} - \bar{y}_{t+1} = \alpha(y_t - \bar{y}_t) - \sigma(i_t - \pi_t - \bar{r}) + \delta z_{t+1} + \eta_{t+1} \quad (5)$$

$$z_{t+1} = \theta_1 \pi_t + \theta_2(y_t - \bar{y}_t) + \theta_3 z_t + \nu_{t+1}, \quad (6)$$

The model consists of a Phillips curve, which relates inflation to the output gap and an IS curve which indicates the dependence of the output gap on the interest rate, that is the policy instrument.  $z_t$  serves as a stand-in for other, possibly endogenous, variables affecting output and inflation, and is determined according to the third equation in the model.  $(\epsilon_{t+1}, \eta_{t+1}, \nu_{t+1})$  refer to normally-distributed economic shocks with mean zero and known variance.  $(\alpha, \kappa, \gamma, \sigma, \delta, \theta_1, \theta_2, \theta_3)$  denote model parameters. Monetary policy suffers from a transmission lag. It takes two periods for a change of the interest rate to affect inflation.

This model may be estimated and then used as a testing ground for optimizing simple outcome- or forecast-based feedback rules as in the above-mentioned model comparison studies. Specifically, the policy response coefficients  $(\phi_\pi, \phi_y)$  and  $(\phi_{\pi,h}, \phi_{y,k})$  in equations (2) and (3), would be chosen to minimize the loss defined by (1) (or its limiting version without discounting) subject to the model defined by equations (4), (5) and (6). For example, the comparison study in Taylor (1999) included a similar model by Rudebusch and Svensson (1999). The role of forecasts in such policy evaluations is consistent with Theil's proposition. Firstly, the forecast-based rule involves a policy response to the rational expectation/forecast of inflation and the output gap conditional on the macroeconomic model including the policy rule. Secondly, the optimization exercise with the outcome-based rule can be interpreted as a rational forecast of output and inflation variability conditional on the model and this particular rule. Of course, in the applications discussed later in this chapter, we will also consider state-of-the-art macro models that include forward-looking expectations by households and firms in the economic structure. In this case, policy optimization and associated forecasts will also need to differentiate the case of discretionary policy when private sector expectations do not incorporate policy commitments from the case when institutions are in place that allow for credible commitment.

### Optimal control policy and forecast targeting

An alternative to simple policy rules is given by the *optimal control policy*. Optimal control would imply *choosing a path* of the policy instrument  $i_t$  that minimizes expected losses, defined by equation (1), subject to the model of the economy represented by equations (4), (5) and (6) and the information set  $I_t$ . Optimal control does not impose the particular functional form for policy implied by simple rules such as (2) and (3). However, given that the model considered is linear in the relevant state variables  $(\pi_t, y_t - \bar{y}_t, z_t)$ , and the objective is quadratic in the target variables,  $(\pi, y)$ , the optimal control policy turns out to be a linear function of the states:

$$i_t = \bar{r} + \pi^* + \tilde{\phi}_\pi(\pi_t - \pi^*) + \tilde{\phi}_y(y_t - y_t^*) + \tilde{\phi}_z z_t, \quad (7)$$

where it is assumed that the policy maker observes potential output  $\bar{y}_t$  and sets the target  $y_t^*$  accordingly. Contrary to the simple rules discussed above, the optimal control policy implies a direct interest rate response to all state variables, including  $z_t$ , which stands for many variables that affect output and inflation. The forecast-based rule incorporates an indirect response to all state variables via the inflation and output forecasts, but the functional form of this rule imposes additional restrictions on the coefficients relative to the optimal control policy. The optimal control coefficients  $\tilde{\phi}_\pi$ ,  $\tilde{\phi}_y$  and  $\tilde{\phi}_z$  are nonlinear functions of the structural model and loss function parameters  $(\kappa, \gamma, \alpha, \sigma, \delta, \theta_1, \theta_2, \theta_3, \beta, \lambda)$ . These coefficients are generally different from the response parameters in the simple rules, that is  $(\phi_\pi, \phi_y)$  and  $(\phi_{\pi,h}, \phi_{y,k})$ . Forecasts of future inflation and output deviations from the central bank's targets—conditional on the central bank's model and information set—are used in optimizing the path of the central bank interest rate.

No central bank has publicly announced that it strictly implements an optimal control policy and communicated all the preference and model parameters needed for the policy calculation. Svensson (1999, 2003) has proposed to mimic the optimal control policy by pursuing a so-called *forecast targeting rule*. This rule is expressed in forecasts of the target variables output and inflation, rather than directly implementable interest rate prescriptions. In his terminology the loss function with inflation and the output gap in equation (1) is referred to as flexible inflation targeting. He breaks the optimization problem in two steps. First, he derives the first-order conditions with respect to output and inflation conditional on the Phillips curve, equation (4), that determines the economic tradeoff between these two target variables. In the second step, the other model equations are used to derive the interest rate setting. This interest rate setting is equivalent to the optimal control policy defined by equation (7). Svensson (2003) shows that the optimality condition corresponds to,

$$E[\pi_{t+j+1} - \pi^* | I_t] = \frac{\lambda}{\beta\kappa} (\beta E[(y_{t+j+1} - y_{t+j+1}^*) - (y_{t+j} - y_{t+j}^*) | I_t]), \quad j \geq 0. \quad (8)$$

for the case when  $z_t$  is exogenous. This relationship between output and inflation forecasts provides an implicit definition of the optimal control policy. With regard to its practical implementation, Svensson (2003) recommends that *"the central bank staff construct the "feasible" set of forecasts and instrument plans. The decision-making body ... then selects the combination of forecasts that "look best" ..., the best compromise between stabilizing the inflation gap and the output gap."* This recommendation is similar but not identical to another often-used description of inflation forecast targeting, which states that central banks should set policy such that the implied inflation forecast is equal to the central bank's target at some given, constant horizon.

In the last twenty years a number of countries have adopted explicit inflation targeting regimes. They use forecasts extensively in their communication with markets. A possible description of their policy strategy is one in which the stance of policy is adjusted to ensure that the inflation rate is projected to return to target within an acceptable period (see e.g. Leiderman and Svensson, 1995; Bernanke and Mishkin, 1997; Bernanke et al., 1999). The optimal control approach to inflation targeting - often referred to as forecast targeting - is developed in detail in Svensson (2010), Svensson (2011), Woodford (2007) and Woodford (2011).

### An equivalence result

Having presented several different approaches to the use of forecasts in policy design, namely simple outcome-based rules, simple forecast-based rules, optimal control policies and forecast targeting rules, we close by noting an equivalence result that is obtained under restrictive conditions. Specifically, if the parameters  $\gamma$  and  $\delta$  are set to zero, the other endogenous variable(s) denoted by  $z_t$  do not affect inflation or output. Thus, the optimal control policy takes the form of a simple outcome-based rule and can also be expressed as a forecast-based rule with the one-period-ahead inflation forecast:

$$i_t = \bar{r} + \pi^* + \tilde{\phi}_\pi(\pi_t - \pi^*) + \tilde{\phi}_y(y_t - y_t^*), \text{ or} \quad (9)$$

$$i_t = \bar{r} + \pi^* + \tilde{\phi}_{\pi,1}(E[\pi_{t+1}|I_t] - \pi^*) + \tilde{\phi}_{y,0}(y_t - y_t^*). \quad (10)$$

In other words, there is one particular setting of the response parameters in the outcome-based rule,  $(\tilde{\phi}_\pi, \tilde{\phi}_y)$ , a different one in the forecast-based rule,  $(\tilde{\phi}_{\pi,1}, \tilde{\phi}_{y,0})$ , which render these rules identical to the optimal control policy. This setting could also be obtained by minimizing the loss function subject to the model and the particular form of the policy rule.

In sum, if the economic model exactly matches the true macroeconomic relations in the economy, then a central bank that implements the optimal control policy will achieve better or equal stabilization outcomes than simple outcome- or forecast-based rules. However, the optimal control solution is more complicated than either of the simple rules, making it more difficult to communicate to the public. Forecast targeting may help in organizing the implementation of an optimal control policy, but it does not provide an explicit prescription for the instrument setting that can be checked by the public as easily as simple rules. Forecast-based simple rules provide an avenue for taking into account additional information on the state and structure of the economy relative to outcome-based rules. Yet, given that the true structure is unknown, there is a risk that some of this information is misleading. Thus, it is of great interest to compare the robustness of different policy and forecasting approaches under model uncertainty as in (Levin et al., 2003). The interaction of forecast-based policy and economic fluctuations can be studied in structural macroeconomic models, which can also be used to search for efficient and robust policy prescriptions. We will return to this question in section 6.

### Preference and forecast asymmetries

The model we have considered features a quadratic loss function. This loss is symmetric, i.e. deviations of inflation or output above or below the respective target values are equally undesirable from the policy makers' perspective. In practice, central banks may treat such deviations asymmetrically. For example, they might react more aggressively to recessions by lowering interest rates to a greater extent than they would raise interest rates in the event of a boom of the same absolute magnitude. Such decision making would be consistent with an asymmetric loss function that penalizes negative deviations of output from potential more than positive deviations. The policy induced by such preferences would then induce an upward bias in inflation (see Nobay and Peel (2003) and Surico (2007) for analytical expositions and Surico for an empirical analysis of Federal Reserve policy).

An important consequence of asymmetric loss functions would be an asymmetry in forecasts. For example, Patton and Timmermann (2007) analyse Federal Reserve output growth forecasts and find that they are suboptimal under a symmetric loss function. However, the forecasts are optimal if overpredicting output growth is more costly than underpredicting it.

Asymmetric loss may also be an important feature of fiscal policy making and exert an influence on government budget forecasts. Empirical evidence is provided by Elliott et al. (2005). They analyze International Monetary Fund and OECD forecasts of budget deficits in the G7 countries. They argue that underestimating budget deficits yields different costs than overestimating budget deficits (see also Artis and Marcellino, 2001; Campbell and Ghysels, 1995). The shape of a forecast loss function might be influenced by political pressure of member countries or the budgetary discipline that these forecasts might impose. Elliott et al. (2005) find that the IMF and OECD forecasts systematically overpredict budget deficits, a finding which would be in line with the budgetary discipline argument. For some countries they find that underpredictions of budget deficits are viewed up to three times costlier than overpredictions. If policy makers in the member countries want to use these forecasts, but do not have the same loss function as the forecaster they would need to adjust the forecasts.

### **3 Examples of forecasts produced at fiscal authorities and central banks**

**Table 1** lists a number of forecasts that are of particular relevance for monetary and fiscal policy making and regularly published by policy institutions such as the Board of Governors of the Federal Reserve System, the Congressional Budget Office, the European Central Bank, the European Commission and other central banks and international organizations.

#### **3.1 Forecasts for fiscal policy purposes**

As discussed in the introduction to this paper the *Budget and Economic Outlook* of the Congressional Budget Office is an essential part of the federal budgeting process in the United States. The forecasts are published every year in January and submitted to the House and Senate Committees on the Budget. The report is updated mid-year. In addition, the CBO publishes an analysis of the President's Budgetary Proposals for the upcoming fiscal year. The CBO forecasts play an important role in ensuring that the budgetary developments remain in accordance with any targeted deficit or surplus. Assumptions regarding future policy underlying the CBO's baseline forecast are based on rules established in The Balanced Budget and Emergency Deficit Control Act of 1985 (Public Law 99-177).<sup>11</sup> The baseline estimate assumes that existing policies and laws continue in the future. Specifically, direct spending and receipts are assumed to continue at the level prescribed by current law. Discretionary

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<sup>11</sup>The rules expired on September 30, 2006, but the CBO continues to follow the methodology prescribed in the law for establishing baseline projections.

spending is assumed to continue at the level of current year spending adjusted for inflation and other factors. CBOs baseline projections are not intended to be a forecast of future budgetary outcomes, but are supposed to serve as a neutral benchmark. In addition, CBO publishes alternative scenarios that include changes in future policies.

In the European Union and the euro area fiscal policy is conducted by national governments. However, the European Commission provides forecasts in a publication called European Economic Forecast. Forecasts are published twice a year with some interim updates for the largest member states. Forecasts are computed for the individual countries, the euro area, the EU, candidate countries and some non-EU countries. The forecast covers 180 variables. Individual country forecasts are computed by country desks using different economic models and econometric tools. The forecasts for the euro area and the EU are constructed by aggregating the country forecasts. The government of the United Kingdom recently founded a new Office for Budget Responsibility (OBR) in May 2010 that is tasked to assess public finances for each government budget similar to the CBO in the United States. It produces economic and fiscal forecasts and evaluates the long-run sustainability of public finances. Similar to the CBO the OBR publishes reports analyzing the accuracy of its own forecasting record.

Table 1: Examples of important forecasts

	US	Euro Area	UK	International
fiscal policy	CBO:  Budget and Economic Outlook	European Commission:  European Economic Forecast	Office for Budget Responsibility: Economic and Fiscal Outlook	
monetary pol.	FRB (staff): Greenbook/Tealbook  FOMC: FOMC minutes	Eurosystem (staff): Monthly Bulletin (ECB + National Central Banks)	Bank of England: Inflation Report	
general	Philadelphia Fed Survey of professional forecasters	ECB ECB Survey of Professional Forecasters		IMF World Economic Outlook OECD Economic Outlook

### 3.2 Forecasts for monetary policy purposes

In the following we provide a more detailed description of the production of forecasts at central banks. We focus especially on the Federal Reserve and the European Central Bank, because we will use those forecasts later on to check whether they influence actual policy decisions. A more general though somewhat dated overview of forecasting practices at central banks is given in Robertson

(2000).

### **Federal Reserve forecasts**

The Federal Reserve publishes information on forecasts obtained via a regular poll of FOMC members, which include the Governors of the Federal Reserve System and the Presidents of the regional Federal Reserve Banks, prior to FOMC meetings. The semi-annual monetary policy reports to U.S. Congress (the so-called Humphrey-Hawkins reports) have presented information on the range and central tendency of FOMC members' forecasts since 1979. Since November 2007 the FOMC has compiled and released these forecast ranges and central tendencies four times a year. The central tendency excludes the three highest and three lowest projections. FOMC members are asked to predict economic growth, the unemployment rate, and core and overall price inflation as measured by the personal consumption expenditures deflator (PCE). Prior to 1998 the inflation forecasts concerned the consumer price index (CPI). The FOMC members' projections should be based on "*appropriate monetary policy*" that is defined "*as the future path of policy that the participant deems most likely to foster outcomes for economic activity and inflation that best satisfy his or her interpretation of the Federal Reserve's dual objectives of maximum employment and stable prices.*"<sup>12</sup> The horizon of the forecasts used to be for the current and next year. Since November 2007, FOMC members are asked to provide a projection for an additional year into the future as well as a long-run projection. This long-run projection implicitly provides information on FOMC perceptions regarding long-run potential growth, the natural unemployment rate and the FOMC's desired long-run inflation rate.

In addition, the staff of the Federal Reserve Board (FRB) in Washington, DC provides a forecast of economic developments for every meeting of the Federal Open Market Committee (FOMC). This document used to be called the Greenbook due to its green cover and is nowadays referred to as the Tealbook.<sup>13</sup> In contrast to the FOMC members' projections, the FRB staff forecasts are confidential. They are only meant to inform the discussion among FOMC members. The forecasts are made available to the public with a five year lag. An online archive of past Greenbook data sets is available from the Federal Reserve Bank of Philadelphia.

The forecasts are conditioned on a specific future path of the federal funds rate – the primary policy instrument of the FOMC. It is often assumed that the federal funds rate will be kept constant at the most recent level. At other times a decreasing or increasing path is assumed, especially if a constant interest rate path would be implausible. We will discuss different conditioning assumptions in detail in section 5.4.

As explained by Edge et al. (2010), Robertson (2000), and Reifschneider et al. (1997) the Federal Reserve staff forecast is a judgmental projection that is derived from quantitative data, qualitative information, different economic models, and various forecasting techniques. The forecast does not

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<sup>12</sup>See, for example, Minutes of the Federal Open Market Committee April 26-27, 2011, Summary of the Economic Projections, Page 1.

<sup>13</sup>Until summer 2010 forecasts and monetary policy alternatives were summarized in two different documents: the Greenbook and the Bluebook. These are now merged in the Tealbook.



result from a mechanical run of any large-scale macroeconomic model; nor is it derived directly by add-factoring any such model. Instead, it relies heavily on the expertise of sector specialists and senior advisers. The Federal Reserve's structural macroeconomic model of the U.S. economy — the so-called FRB/US model<sup>14</sup> — is only one of the tools used as an input into the deliberations that lead to the Greenbook/Tealbook projection. According to the above-mentioned descriptions of the FRB staff forecasting process, FRB/US model forecasts are prepared at the same time as each Greenbook forecast and for the same projection horizon. Furthermore, the model forecast is conditioned on the same path for the federal funds rate as the Greenbook projection.

A forecast coordinator provides sector specialists with a set of conditioning assumptions and forecasts as a starting point. On this basis, staff economists that specialize on specific sectors create a first set of forecasts for a variety of economic variables. They might use a range of different statistical and econometric techniques and models and expert knowledge. Furthermore, all regional Federal Reserve Banks collect information on current regional conditions that are presented in the Beigebook and can also help in forming a view about the current state of the U.S. economy. Additionally, econometric methods that can process unbalanced data sets of differing frequency are used in creating an estimate of current conditions, in other words, a nowcast that can serve as a starting point for forecasts. The different assessments are aggregated with the help of the forecast coordinator and staff meetings into projections for output, inflation and interest rates. Afterwards, individual sector forecasts are checked to be consistent with these aggregate forecasts. This process goes on until sectoral and aggregate forecasts converge (Reifschneider et al., 1997).

The Greenbook/Tealbook forecast contains a wide variety of variables that are grouped into expenditure, employment and production, income and savings and prices and costs categories. There are also detailed projections of federal sector accounts. Real GDP and CPI-inflation are projected for major industrial and developing countries. The FRB/US model is used to compute confidence intervals around the judgmental point forecast and alternative scenarios for some key aggregates like real GDP, the unemployment rate, and a core personal consumption expenditure price index. To this end, the core model is add-factored in order to replicate the final Greenbook point forecast over the forecast horizon. The add-factored version of the model is then used for various exercises, such as generating intervals around the Greenbook forecasts based on stochastic simulations and occasionally for producing longer-run forecasts at horizons beyond two years.

### **European Central Bank forecasts**

As to the euro area, the Eurosystem staff—that is the staff of the European Central Bank (ECB) together with the staff of the euro area national central banks—prepare macroeconomic projections twice a year. Furthermore, the ECB's staff prepares two additional projections per year so that euro area projections are available at a quarterly frequency. These projections serve as an input to the ECB Governing Council meetings and are made public afterwards in the ECB's Monthly Bulletin. There is no public information on the personal forecasts of members of the ECB Governing Council.

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<sup>14</sup>See Brayton and Tinsley (1996) and Reifschneider et al. (1999) for descriptions of the FRB/US model.

The joint forecasting process of ECB staff and national central banks' (NCB) staff is described in European Central Bank (2001). This joint group is called the Working Group on Forecasting (WGF) and includes macroeconomic and econometric experts. They produce detailed macroeconomic projections under the responsibility and guidance of a Monetary Policy Committee (MPC). This committee consists of senior staff representatives of the ECB and the national central banks. National central banks compute forecasts of GDP growth, its components, HICP inflation and the GDP deflator and possibly other variables in their countries. Country forecasts are then aggregated to euro area forecasts in a process that involves several types of consistency checks. The forecast rounds done solely by the ECB staff are called macroeconomic projection exercises (MPEs) and the joint projections with the national central banks are called BMPEs (broad MPEs).

This process involves three steps: (i) setting the assumptions underlying the exercise; (ii) a process of overview at area-wide level with consistency checks and peer review of individual country results that leads to a set of projection figures; (iii) preparation of a report for the Governing Council and the publication of the forecasts in the ECB's monthly bulletin.

With regard to conditioning assumptions, national central bank staff and ECB staff decide on a joint set of exogenous time paths for interest rates, exchange rates, the international environment, fiscal variables and commodity prices. In particular, paths for interest rates and commodity prices are based on market expectations derived from futures rates.

Afterwards each national central bank computes a forecast for its country, whereas ECB staff prepare a set of projections for the individual countries as well as for the euro area as a whole. The ECB's euro area projection is a consistent aggregation of its country assessments. The national central banks use a variety of models, econometric methods and sectoral or country expertise. The combination of model-based and judgemental-based information may also vary across countries.

Then an iterative process of consistency checking between the ECB's area-wide forecast and the aggregation of the NCB forecasts is started. This process relies on meetings of NCB and ECB experts, and importantly, also on analysis using the area-wide macroeconomic model of the ECB research directorate.<sup>15</sup> In addition, consistency checks are conducted with respect to trade volumes and prices as well as financial flows and consolidated balance sheets of monetary financial institutions in the euro area.

The resulting Eurosystem staff projections serve as an input to the ECBs Governing Councils meetings. Forecasts of variables that are published in the Monthly Bulletin include HICP inflation, real GDP growth and its main components over for the current and the next year. The projections are published in the form of uncertainty ranges corresponding to 57.5% probability bands.<sup>16</sup> Ranges are wider for longer forecast horizons reflecting the increased uncertainty. The ranges reflect uncertainty due to unforeseeable shocks and imprecise parameter estimates as well as departures from the

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<sup>15</sup>A description of the area-wide model is available in Fagan et al. (2005). In 2008 this model was replaced with a New-Area-Wide model that is presented in Christoffel et al. (2008).

<sup>16</sup>By contrast, the ranges of FOMC forecasts published by the Federal Reserve indicate the level of disagreement between FOMC member point forecasts rather than economic uncertainty bands.

conditioning assumptions of the baseline forecast. In addition specific scenarios deviating from the baseline conditioning assumptions are computed. For example, Eurosystem staff may compute a forecast where the growth rate for the United States is assumed to be much lower than in the baseline case or where the oil price is assumed to be higher. Many national central banks also publish the projections for their economies. Forecasts are published together with a written statement that explains economic developments and the surrounding uncertainty.

### **Inflation targeting central banks**

At inflation-targeting central banks such as, for example, the Reserve Bank of New Zealand, the Central Bank of Chile, the Bank of England, Sveriges Riksbank or the Bank of Norway the inflation forecast takes center stage in the communication with the public. Their forecasts are not just staff, but official forecasts. They are published and discussed regularly with the stated aim of influencing and anchoring private sector expectations. For example, announcing a certain inflation target and publishing an official forecast that illustrates that the central bank plans to do what is necessary to reach that target can induce price setters to adopt this forecast in their considerations.

While the Fed Greenbook and the Eurosystem forecasts are associated with the staff and not the policy makers, the official forecasts of inflation targeting central banks involve a much closer collaboration of staff and policy makers. The reason is that the inflation forecast typically serves as an intermediate policy target. In this context, the consequences of particular conditioning assumptions need to be considered especially carefully. We will discuss their consequences more thoroughly in section 5.4.

A thorough review of forecasting practices at inflation targeting central banks is beyond this chapter.<sup>17</sup> To pick an example, we review the procedures employed at the Bank of England. Of course, there are differences in the forecasting processes employed by different inflation targeters. However, all of them publish detailed inflation forecasts that reflect the views of policy makers in an official document often called inflation report.

The published forecast of the Bank of England is the outcome of a joint forecasting process of staff and the Monetary Policy Committee (MPC).<sup>18</sup> In a series of meetings between the MPC and the bank's staff the forecasts are constructed, discussed and adjusted until they represent the views of the MPC. The forecast involves judgment as well as a variety of economic models.<sup>19</sup> The Bank of England mainly employs a suite of five models. The core model has been replaced in 2005 by the new Bank of England Quarterly Model (BEQM) (Bank of England, 1999, 2004). The suite of

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<sup>17</sup>In this regard, the reader is referred to the chapter on inflation targeting in the forthcoming Handbook of Monetary Economics by Svensson (2010).

<sup>18</sup>The MPC is the Bank's main policy-making committee not to be confused with the MPC committee in the Eurosystem which involves staff experts charged with producing a joint forecast for the consideration of euro area policy makers.

<sup>19</sup>In section 5.4 we will demonstrate a formal approach to include judgement or off-model information via conditioning assumptions into structural model forecasts. Such a formal approach is used for example at the Central Bank of Norway (Bache et al., 2010). At most central banks, however, the process of including judgement and conditioning assumptions is less formal.

models includes small-open economy New Keynesian structural models, small vector autoregression models, single-equation regression models like Phillips curve models but also medium-scale dynamic stochastic general equilibrium (DSGE) models and larger-scale structural macroeconomic models. The BEQM is a macroeconometric model that combines a DSGE model that is consistently derived from microeconomic optimization behavior of households and firms with additional dynamics that reflect short-run correlations not matched by the core DSGE model. The BEQM is the main tool employed by the Bank of England staff and the MPC to construct the projections for the inflation reports. It serves as a reference point to organize discussions about recent and projected economic dynamics. However, the final projections are not a mechanical output from the model, but include a high degree of judgement by the MPC.

The Bank of England's forecasts are presented as fan charts that represent uncertainty about future economic developments and the conditioning assumptions. The forecast horizon is up to three years ahead. The fan charts of the Bank of England offer more detail on the degree of uncertainty than the Eurosystem forecasts. First, confidence intervals are computed based on past forecast errors. Then the MPC comments on these intervals and they are adjusted accordingly to reflect asymmetric perceptions of upward and downward risks. In the case of upward risks, raising the interest rate would become more likely, than when the MPC's assessment points to symmetric uncertainty or downward risks to the inflation forecast. The adjustment of the uncertainty bands by the MPC could be useful to account for structural changes or additional variables not taken into account by the model and past forecast errors.

### **International institutions**

Other important forecasts that receive considerable attention by governments and the press are the International Monetary Fund's (IMF) World Economic Outlook and the Organization for Economic Cooperation and Development (OECD) Economic Outlook. The IMF's World Economic Outlook includes analysis and projections of the main macroeconomic aggregates for all IMF member countries and is published twice a year. It is an integral element of the IMF's surveillance process. The OECD's Economic Outlook is a similar publication that covers the OECD member countries and is also published twice a year.

## **4 Empirical evidence that policymakers' decisions respond to forecasts**

Do policymakers adjust their decisions in response to changes in the forecast? Answering this question requires an empirical investigation. Of course, it is easiest to search for such a link in an environment in which decision makers are exposed to a particular forecast on a regular basis and shortly thereafter make a policy decision that immediately becomes public. Thus, it is most easily tested in the context of central bank interest rate policy. We focus on the central banks in charge of the two most widely used currencies, the U.S. Federal Reserve and the European Central Bank. After reviewing findings from the literature we conduct additional new empirical tests.

## 4.1 Federal Reserve interest rate decisions

### Literature

Central bank policy in the United States is primarily concerned with setting a target for the federal funds rate. Soon after Taylor (1993) showed that the federal funds rate path between 1987 and 1992 was matched very well by a simple rule that had been optimized in a model comparison exercise, Federal Reserve staff started preparing Taylor rule charts as part of the regular information package received by the FOMC (Kohn, 2007).<sup>20</sup> These charts included rules with Taylor’s original coefficients on inflation and the output gap and rules with estimated coefficients similar to those in Judd and Rudebusch (1998). By 1997 this information also included rules based on (real-time) FOMC forecasts of inflation and unemployment that were shown to exhibit a better empirical fit than outcome-based rules by FRB economists Lindsey, Orphanides and Wieland (1997).<sup>21</sup> In 2007 William Poole, then-President of the Federal Reserve Bank of St. Louis and member of the FOMC characterized the use of the Taylor rule by the FOMC as follows:

*“The FOMC, and certainly John Taylor himself, view the Taylor rule as a general guideline. Departures from the rule make good sense when information beyond that incorporated in the rule is available. For example, policy is forward looking; which means that from time to time the economic outlook changes sufficiently that it makes sense for the FOMC to set a funds rate either above or below the level called for in the Taylor rule which relies on observed recent data rather than on economic forecasts of future data.”*  
(Poole (2007), (p. 6))

Many other studies have estimated Taylor-style rules using forecasts of U.S. data since the mid 1990s. Most of these studies included an interest rate smoothing term (cf. Clarida et al., 1998, 2000).<sup>22</sup> Clarida et al. (2000), for example, compare forecast-based rules for the period before Paul Volcker’s Fed chairmanship with the Volcker-Greenspan period using forecasts implied by U.S. data of 1997 vintage.

Many of the rules estimated in these studies are nested by following specification:

$$i_t = \rho i_{t-1} + (1 - \rho)[i^* + \beta(E_t \pi_{t+h_\pi} - \pi^*) + \gamma E_t y_{t+h_y}] + \epsilon_t, \quad (11)$$

where  $i_t$  denotes the nominal interest rate,  $\pi_t$  the rate of inflation and  $y_t$  the output gap, which is replaced with the unemployment rate in Lindsey et al. (1997) and Orphanides and Wieland (2008).

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<sup>20</sup>One of the authors’ of this chapter (Wieland) was the staff economist responsible for updating this rules package regularly for the FOMC from 1996 to 2000.

<sup>21</sup>This working paper was presented publicly at several occasions but not submitted for publication. It is available for download from [www.volkerwieland.com](http://www.volkerwieland.com).

<sup>22</sup>Sack and Wieland (2000) discuss several reasons why central banks tend to smooth interest rates. Rudebusch (2002) argues that a large and significant interest rate smoothing coefficient is the result of a misspecified monetary policy rule. However, tests by English et al. (2003), Castelnuovo (2003) and Gerlach-Kristen (2004) provide further support for interest-smoothing.

Inflation and the nominal interest rate are measured at annual rates in percentage points.  $\rho$ ,  $\beta$  and  $\gamma$  denote the response parameters.  $\pi^*$  is the inflation target and  $i^*$  the equilibrium nominal interest rate when inflation and output equal their respective target values.  $\epsilon_t$  stands for a monetary policy shock which captures deviations from the systematic policy response to output and inflation. The parameters  $h_\pi$  and  $h_y$  denote forecast horizons measured in quarters that correspond to the degree of forward-lookingness of the central bank. The policy rule (11) also nests equations (2) and (3) from section (2.2).

**Table 2** reports estimation results from the above-mentioned studies for rules corresponding to equation (11). Lindsey et al. (1997) identified a strong policy response to FOMC forecasts of inflation and unemployment with coefficients of 2.23 and -2.22 respectively. A rule-of-thumb for comparing the unemployment response coefficient with an output gap coefficient using Okun's law is to multiply with -0.5, which would imply an output gap coefficient near unity. Thus, the systematic policy response to inflation and output forecasts is quite a bit larger than the response to recent outcomes implied by the original Taylor rule coefficients of 1.5 and 0.5 respectively. However, the interest-rate-smoothing coefficient of 0.38 implies that the funds rate only adjusts partially towards this policy prescription within one quarter. Since FOMC forecasts were only produced semi-annually the estimation of Lindsey et al. (1997) only uses two observations per year. The forecast horizon is three quarters.<sup>23</sup>

Clarida et al. (2000) consider forecast horizons of 1 and 4 quarters for the rate of inflation, and a horizon of 1 quarter for the output gap. They use quarterly data of 1998 vintage and identify forecasts using generalized method of moments estimation.<sup>24</sup> Clarida et al. (2000) find that the interest rate response to inflation during the pre-Volcker period, that is from 1960 to 1979 was not sufficient to achieve stabilization. It fails the so-called Taylor principle. An increase of inflation (expectations) is followed by a less than one-to-one increase in the nominal interest rate and thus a decline in the real interest rate. Such a decline in the real rate of interest would further stimulate economic activity, generate additional output and further upward pressure on prices resulting in faster inflation. For the Volcker-Greenspan era the inflation response coefficient is larger than 1 and consequently satisfies the Taylor principle. Over this period, the FOMC raised interest sufficiently in response to inflation forecasts so as to ensure a stabilizing impact on inflation. The response to the four quarter ahead inflation forecast is estimated to be greater than the response to the one quarter ahead inflation forecast.

Orphanides (2001) points out that actual policy decisions are better captured by using the data that was available to policy makers at that time. He analyzes the period from 1987-1992, the original sample considered by Taylor (1993). In a first step he compares interest rate rules for different forecast horizons using ex post revised data. In this case, he finds that a specification with contemporaneous inflation and output gap estimates fits the data best. In a second step Orphanides uses Greenbook forecasts of inflation and the output gap to estimate the policy rule. With this real-time data speci-

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<sup>23</sup>The exact derivation of the constant-three-quarter ahead forecasts from the available FOMC forecasts is discussed in the next subsection.

<sup>24</sup>A possible justification for the differential horizons is that output affects inflation with a lag.

Table 2: Examples of estimated monetary policy parameters for different forecast horizons

Source	sample	$h_\pi^1$	$h_y^1$	$\rho$	$\beta$	$\gamma$
U.S.						
Lindsey et al (1997): real-time	1988Q1-1996Q3	3	3	0.38 <sup>2</sup>	2.23	-2.22 <sup>3</sup>
Clarida et al. (2000)	1960Q1-1979Q2	1	1	0.68	0.83	0.27
Clarida et al. (2000)	1979Q3-1996Q4	1	1	0.79	2.15	0.93
Clarida et al. (2000)	1960Q1-1979Q2	4	1	0.73	0.86	0.34
Clarida et al. (2000)	1979Q3-1996Q4	4	1	0.78	2.62	0.83
Orphanides (2001): real-time	1987Q1-1992Q4	1	1	0.63	0.39	1.02
Orphanides (2001): revised	1987Q1-1992Q4	1	1	0.73	1.49	1.05
Orphanides (2001): real-time	1987Q1-1992Q4	4	4	0.56	1.62	0.82
Orphanides (2001): revised	1987Q1-1992Q4	4	4	0.95	3.72	2.96
Orphanides and Wieland (2008): real-time	1988Q1-2007Q3	3	3	0.39 <sup>2</sup>	2.48	-1.84 <sup>3</sup>
Euro area						
Gerdesmeier and Roffia (2005): revised	1999Q1-2003Q1	4	0	0.81 <sup>4</sup>	0.64	1.44
Gerdesmeier and Roffia (2005): real-time	1999Q1-2003Q1	4	0	0.98 <sup>4</sup>	2.13	1.63
Gerdesmeier and Roffia (2005): real-time	1999Q1-2003Q1	8	0	0.95 <sup>4</sup>	1.87	1.70
Gorter et al. (2008): real-time	1997Q1-2006Q4	4	4	0.89 <sup>4</sup>	1.67	1.65
Gorter et al. (2008): revised	1997Q1-2006Q4	4	4	0.96 <sup>4</sup>	0.04	0.86
Gerlach (2007) <sup>5</sup>	1999Q2-2006Q2	4	4	-0.79 <sup>6</sup>	-0.60 <sup>7</sup>	2.20 <sup>8</sup>

Notes: <sup>1</sup> the forecast horizons  $h_\pi$  and  $h_y$  always refer to a quarterly frequency regardless whether the data is monthly or quarterly.

<sup>2</sup> The interest rate lag corresponds to two quarters rather than one quarter.

<sup>3</sup> Lindsey et al. (1997) and Orphanides and Wieland (2008) use forecasts of the unemployment rate instead of the output gap. A rule-of-thumb for comparing the unemployment response coefficient with an output gap coefficient using Okun's law is to multiply with -0.5.

<sup>4</sup> The interest rate lag is one month rather than one quarter.

<sup>5</sup> Gerlach (2007) estimates an ordered probit model so that the size of the parameters is not directly comparable to the other results in the table. The equation includes in addition to the parameters in the table the lagged change in the interest rate and the exchange rate.

<sup>6</sup> Reaction to a one month lagged interest rate rather than one quarter.

<sup>7</sup> The negative inflation reaction found by Gerlach (2007) is not significant.

<sup>8</sup> Gerlach (2007) uses a measure of expected economic growth instead of the output gap.

fication he finds that policy rules with inflation and output gap forecasts fit the data better than with inflation and output gap nowcasts. In Table 2 we compare his results for one-quarter-ahead and four-quarter-ahead forecasts with real-time and revised data. Estimates with revised data overestimate the response to inflation. Estimates with one-quarter-ahead forecasts do not fulfill the Taylor principle. However, the response to the four-quarter-ahead inflation forecasts is stabilizing with an estimated parameter higher than unity. Orphanides (2001) also considers other forecast horizons and finds that the coefficient on inflation increases with the horizon, while the coefficient on the output gap decreases. He notes that the forward-looking specification captures the contours of the federal funds rate path

considerably better.

Orphanides and Wieland (2008) have published updated and extended results regarding the interest rate rules in the Lindsey et al. (1997) study with FOMC forecasts. They confirm the earlier finding of a strong response of the funds rate to FOMC inflation and unemployment forecasts. Estimated values are surprisingly close to the Lindsey et al estimates with 10 years of additional data. A rule with FOMC forecasts fits the data much better than an outcome-based rule. We will analyze and extend the the estimation of Orphanides and Wieland (2008) in more detail in the next subsection.

### **New empirical estimates**

On the occasion of the January 2010 meeting of the American Economic Association, Federal Reserve Chairman Ben Bernanke discussed the implications of Taylor-style policy rules for monetary policy during the housing bubble and the financial crisis and stated:

*“ ..., because monetary policy works with a lag, effective monetary policy must take into account the forecast values of the goal variables, rather than the current values. Indeed, in that spirit, the FOMC issues regular economic projections, and these projections have been shown to have an important influence on policy decisions (Orphanides and Wieland (2008))”* (Bernanke, 2010, p. 8).

Thus, in the following we review and extend the Orphanides and Wieland (2008) study to shed further light on the finding that FOMC policy is best described with an interest rate rule based on FOMC forecasts. The range and a central tendency of the forecasts from the FOMC members are available in the Humphrey-Hawkins reports which are presented in February and July of each year. As noted earlier, there is no information available on the FOMC’s assessment of the output gap. For this reason, Orphanides and Wieland (2008) use the unemployment rate forecasts of the FOMC members as a measure of the level of economic activity. Assuming a constant NAIRU estimate, which is subsumed in the regression intercept, the unemployment rate forecast captures anticipated movements in the unemployment gap. Interestingly, Orphanides and Wieland (2008) also estimate rules with the GDP growth forecasts of FOMC, but find that the empirical fit then deteriorates relative to rules with the unemployment forecast.

The estimated rules require constant-horizon forecasts at the time of the policy decisions which do not exactly correspond to the forecast horizon of the available FOMC forecasts. Constant horizon forecasts are computed by appropriately averaging available FOMC forecasts and recent outcome data. We illustrate the derivation of such constant-horizon forecasts in the context of our estimation of forecast-based rules in the euro area in the next subsection. For the estimation with FOMC forecasts we follow Orphanides and Wieland (2008) in comparing rules with three-quarter-ahead forecasts to rules with outcomes from the preceding quarter, with and without interest rate smoothing. These rules are nested in the following specification:

$$i_t = \rho i_{t-1} + (1 - \rho)[\alpha + \beta E_t \pi_{t+h} + \gamma E_t u_{t+h}] + \epsilon_t, \quad (12)$$



It corresponds to equation (11) for  $h = 3$  and  $h = -1$ . The intercept term  $\alpha = i^* - \beta\pi^* - \gamma u^*$  includes the perceived equilibrium nominal interest rate, the inflation target and the perceived natural unemployment rate.

**Figure 1** displays the fitted values of the rules with outcomes (dashed line) and forecasts (dotted line) relative to the actual funds rate target (solid line) decided at each of the February and July FOMC meetings from 1988 to 2010. The rules shown in the upper panel are estimated without interest-rate smoothing ( $\rho = 0$  in equation (12)), while the rules in the lower panel include an estimated degree of interest-rate-smoothing ( $\rho > 0$ ). The parameters are estimated based on the sample from 1988 to 2007. The implications of the rules are then simulated forward using the FOMC forecasts up to the end of 2010.

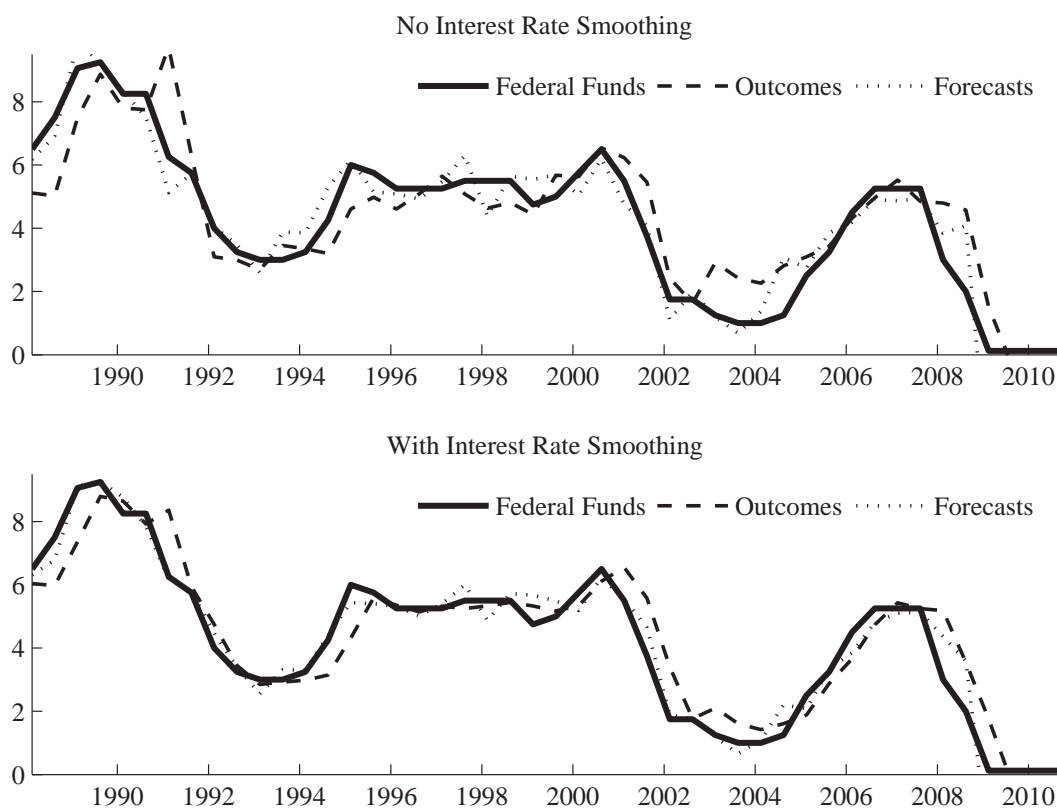


Figure 1: FOMC interest rate reaction functions: Outcomes vs FOMC forecasts

From the estimates without interest smoothing in the upper panel, it is directly apparent that the prescriptions from the forecast-based rule are much closer to actual decisions than those from the outcome-based rule. Not surprisingly, the interest rate rules with smoothing in the lower panel are closer the actual funds rate path. Even so, the forecast-based rule continues to fit better than the outcome-based rule. Orphanides and Wieland (2008) identify five periods during which FOMC forecasts provide a better explanation of policy decisions. Around 1988 and 1994 the FOMC raised interest rates preemptively as it expected inflation to increase in the future. In those periods, the

outcome-based rules respond more slowly, while the forecast-based rules fit almost exactly.

In 1990/1991 and in 2001 the FOMC decreased interest rates as it expected a downturn of the economy. The forecast-based rules capture this anticipation, while the fit of the outcome-based rules is not as good. Finally, in 2002/2003 the forecast-based policy rules indicate lower interest rates than the outcome-based rules, consistent with actual policy. As explained by Orphanides and Wieland (2008) the lower rate prescriptions are partly driven by a switch of the FOMC from forecasting CPI inflation, to forecasting PCE and then core PCE inflation. The PCE forecasts at the time suggested a threat of deflation. By contrast, private sector CPI forecasts would have implied higher interest rate prescriptions throughout this period. In sum, these episodes provide further support for forecast-based rules as a description of actual Federal Reserve Policy consistent with the earlier quotes of FOMC members Ben Bernanke and William Poole.

Table 3: Interest Rate Rules with FOMC Forecasts of Inflation and Unemployment vs Outcomes: 1988-2007

	no interest smoothing			with interest smoothing		
	$\pi_{t-1}, u_{t-1}$	$\pi_{t+3}, u_{t+3}$	$\pi_{t+3}, u_{t-1}$	$\pi_{t-1}, u_{t-1}$	$\pi_{t+3}, u_{t+3}$	$\pi_{t+3}, u_{t-1}$
$\alpha$	8.29 (6.14,10.79)	6.97 (5.22,8.30)	6.56 (5.60,7.61)	10.50 (5.07,27.28)	8.25 (6.73,10.24)	6.81 (5.56,8.33)
$\beta$	1.54 (0.98,2.21)	2.34 (2.02,2.57)	2.20 (1.96,2.33)	1.29 (-0.64,2.47)	2.48 (2.14,2.65)	2.23 (1.91,2.38)
$\gamma$	-1.40 (-1.91,-0.99)	-1.53 (-1.75,-1.22)	-1.40 (-1.60,-1.23)	-1.70 (-3.93,-0.79)	-1.84 (-2.17,-1.55)	-1.46 (-1.67,-1.26)
$\rho$	0	0	0	0.69 (0.24,0.91)	0.39 (0.29,0.54)	0.24 (0.04,0.45)
$R^2$	0.75	0.92	0.94	0.85	0.96	0.95
$\bar{R}^2$	0.74	0.91	0.94	0.84	0.96	0.95

Notes: Parameters are estimated using nonlinear least squares for the case  $\rho \neq 0$ . 95% confidence bands are shown in brackets and are computed using a moving block bootstrap with 5000 repetitions and a block size of 4 observations.

**Table 3** reports the parameter values underlying the rules shown in **Figure 1**. In addition to the estimation results in Orphanides and Wieland (2008), we report on a specification that includes inflation forecasts together with unemployment outcomes. Policy rules with forecasts of inflation and outcomes of real economic activity have been considered in the literature because they account for the conventional wisdom that monetary policy changes are transmitted more quickly to economic activity than to inflation (see e.g. Bernanke and Mihov, 1998).

The parameter estimates indicate that all three specifications satisfy the Taylor principle. The reaction to inflation is highest for the specification with forecasts of inflation and the unemployment rate and lowest for the purely outcome-based rule. The response to unemployment is negative and quite large. For the specifications without interest rate smoothing the fit in terms of  $R^2$  and  $\bar{R}^2$  is

lowest for the outcome-based rule and highest for the rule with a response to the inflation forecast and unemployment outcome. For the specifications with interest rate smoothing the fit is highest for the purely forecast-based rule and lowest for the purely outcome-based rule. In the latter case the parameters of the outcome-based rule are estimated with very large confidence bands, while the forecast-based rule is estimated much more precisely. Also, the degree of interest rate smoothing is greater when using outcomes as regressors, which might be taken as a sign of misspecification.

These findings provide evidence that the FOMC bases its interest rate decisions on inflation forecasts, but are not as clear-cut regarding unemployment. Without interest rate smoothing the fit for a rule with unemployment forecasts is very similar to the fit of a rule with unemployment outcomes, though with interest-rate smoothing the rule with unemployment forecasts fits better. In order to further test forecast- vs outcome-based rules we estimate the following specification, which nests both versions as limiting cases:

$$i_t = \rho i_{t-1} + (1 - \rho)[\alpha + \beta((1 - \phi_\pi)\pi_{t-1} + \phi_\pi E_t \pi_{t+3}) + \gamma((1 - \phi_u)u_{t-1} + \phi_u E_t u_{t+3})] + \epsilon_t, \quad (13)$$

The new parameters  $\phi_\pi$  and  $\phi_u$  indicate the relative importance of forecasts and outcomes of inflation and the unemployment rate. We impose the following constraints in estimation:  $0 \leq \phi_\pi \leq 1$  and  $0 \leq \phi_u \leq 1$ .  $\phi_\pi = 1$ , for example, can then be interpreted as evidence that the Fed responds only to inflation forecasts and not outcomes. Orphanides and Wieland (2008) impose  $\phi_\pi = \phi_u = \phi$ , while we also allow these weights to differ. **Table 4** reports the estimates obtained for  $\phi$ ,  $\phi_\pi$  and  $\phi_u$ .

Table 4: The Relative Importance of Forecasts vs Outcomes: FOMC 1988-2007

	no interest smoothing		with interest smoothing	
	$\phi_\pi = \phi_u$	$\phi_\pi \neq \phi_u$	$\phi_\pi = \phi_u$	$\phi_\pi \neq \phi_u$
$\phi$	0.78 (0.55,0.84)		0.94 (0.67,1.00)	
$\phi_\pi$		0.87 (0.61,0.95)		0.93 (0.65,1.00)
$\phi_u$		0.32 (0.00,0.78)		1 (0.35,1.00)
$R^2$	0.94	0.94	0.96	0.96
$\bar{R}^2$	0.93	0.94	0.96	0.96

Notes: Parameters are estimated using nonlinear least squares. The parameters  $\phi$ ,  $\phi_\pi$  and  $\phi_u$  are restricted to be in the range of 0 to 1. 95% confidence bands are shown in brackets and are computed using a moving block bootstrap with 5000 repetitions and a block size of 4 observations.

When restricting the two weights to be equal, we find  $\phi = 0.78$  and  $\phi = 0.94$ , without and with interest-rate-smoothing, respectively. The point estimates are close to one indicating that forecasts are much more important than outcomes in explaining FOMC policy decisions. In both cases, the 95% confidence bands do not include  $\phi = 0$ . With interest rate smoothing,  $\phi = 1$  lies in the 95%

confidence band.<sup>25</sup> Next, we allow for different weights on forecasts for inflation and unemployment. In the absence of interest rate smoothing the weight on the inflation forecast increases further to  $\phi_\pi = 0.87$ . The weight on unemployment forecasts decreases to  $\phi_u = 0.32$ . This finding is in line with earlier results that for specifications without interest rate smoothing a rule with inflation forecasts and unemployment outcomes yields the best fit. However, the specification with interest rate smoothing yields even a higher  $\bar{R}^2$ . In this case, the weight on inflation forecasts is  $\phi_\pi = 0.93$  and thus very close to 1. The 95% confidence band includes 1, but not 0. Furthermore, the point estimate for the unemployment forecast is on the upper bound:  $\phi_u = 1$ . While the 95% confidence band is wider than for inflation, it excludes 0. The latter results provide further evidence that FOMC policy decisions are based on forecast of inflation *and* unemployment rather than on outcomes.

In 2008, the Federal Reserve responded to the worsening of the financial crisis by rapidly lowering nominal interest rates towards near zero levels. Our out-of-sample simulation of forecast-based rules estimated with data through 2007 going forward throughout 2008 captures this policy response fairly well, though the initial decline in mid 2008 lags a bit behind actual decisions. **Figure 2** displays the simulation up to the end of 2010 relative to the actual funds rate target. From 2009 onwards the FOMC has kept the funds rate at 25 basis points. Nominal interest rates cannot be lowered below zero—at least deposit rates—because savers can instead use cash, which pays an interest rate of zero, to store their savings. Since the economic outlook quickly deteriorated further at the end of 2008 and the beginning 2009, the interest rates prescribed by the feedback rules moved far into negative territory. As unemployment and unemployment forecasts increased drastically from about 6% to around 10%, the rules, which exhibit coefficients between 1.5 on outcomes and 2.3 on forecasts, suggested funds rate targets as low as -2% to -5%, respectively.

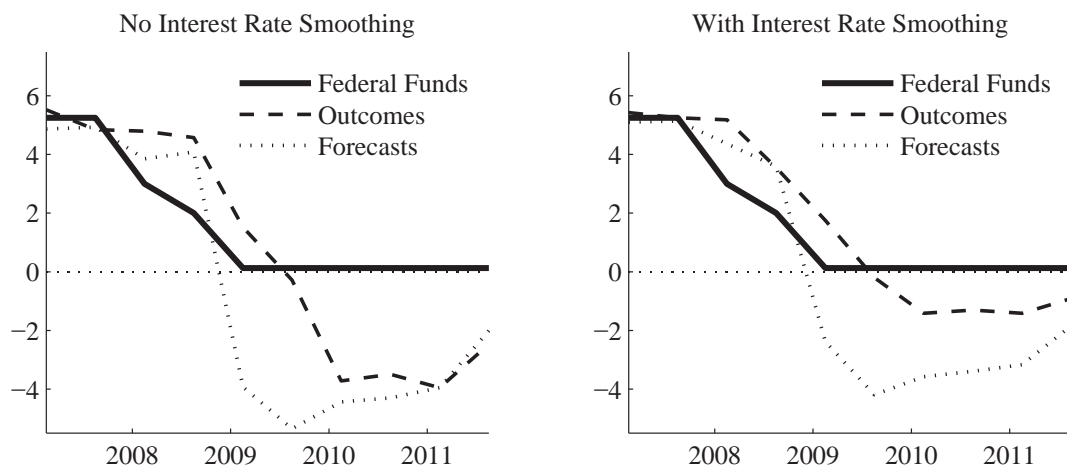


Figure 2: Outcome- vs FOMC Forecast-Based Rules: 2005-2011

With the funds rate near zero, the Federal Reserve did not abstain from further action, but instead

<sup>25</sup>We use a bootstrap algorithm to take account for the parameter restriction  $0 \leq \phi \leq 1$ . As we bootstrap blocks of four observations this allows in addition for serial correlation of the error term up to two years.

took measures that led to a rapid expansion of its balance sheet, including in particular massive direct purchases of assets such as government bonds and mortgage-backed securities, that are referred to as credit and quantitative easing. These policy actions are best understood as a continuation of Federal policy shifting from its usual policy instrument, the federal instrument, to quantity based instruments when the funds rate reaches the zero lower bound. As proposed by Orphanides and Wieland (2000a) policy can be understood as a rule for the quantity of base money when the nominal interest rate is constrained at zero. The response coefficients of such a rule need to be adjusted appropriately taking into account parameters governing money demand and the degree of uncertainty about the effect of quantitative easing on output and inflation. An empirical comparison of the quantitative easing in the United States relative to the negative interest rates prescribed by the forecast-based policy rules would be of great interest but is beyond the present study. Of course, simply extending the estimation of the policy rule with 2009 and 2010 data without accounting for quantitative easing would incorrectly result in a downward bias of the estimated interest rate response coefficients.

## 4.2 ECB interest rate decisions

### Literature

As demonstrated by Gerlach and Schnabel (2000) average interest rates in the EMU countries in the period leading up to the formation of European Monetary Union (EMU), that is from 1990 to 1998 moved very closely with average output gaps and inflation as suggested by the Taylor (1993) rule. The only exception noted by these authors was the period of the crisis of the European Monetary System (EMS) in 1992–93.

By now there are several studies that assess to what extent actual ECB decisions can be described by forecast- or outcome-based interest rate rules. Findings from several of these studies that are nested by equation (11) are reported in **Table 2**. ECB economists Gerdesmeier and Roffia (2005) provide a comprehensive study comparing rules estimated with real-time and final revised data of the euro area as in Orphanides (2001). They use monthly euro area data from 1999 to 2003.<sup>26</sup> Contrary to Orphanides (2001) they find that estimates based on final revised data under-estimate the response coefficients. With real-time data Gerdesmeier and Roffia (2005) find a significant response to survey based expectations for inflation and real economic activity, but not to outcomes of these variables. Thus, they provide evidence that that the ECB is setting interest rates in a forward-looking manner.

Gorter et al. (2008) use euro area Consensus Economics data for expected inflation and output growth. They compare estimates of forecast-based policy rules to outcome-based policy rules with monthly data from 1997 to 2006. They justify starting the sample in 1997 rather than in 1999 as interest rate setting was coordinated during the run-up to the currency union. They find that euro area interest rates are better explained with responses to inflation and output growth forecasts than

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<sup>26</sup>They use an average of five different output gap concepts: linear and quadratic trend measures, the HP Filter and the output gaps provided by the OECD and the European Commission (both are production function approaches). To get monthly output data they interpolate quarterly real GDP using a cubic spline.

outcomes. The coefficient on inflation in the outcome-based policy rule is not significantly different from zero. Thus, their analysis corroborates Gerdesmeier and Roffia (2005) for a longer sample.

Gerlach (2007) estimates an ordered probit model on monthly data from 1999 to 2006 with measures of expected inflation and output growth taken from a poll of forecasters tabulated in "The Economist". He finds that expectations of economic growth play an important role in explaining the ECB's interest rate decisions, but not those regarding inflation. To shed further light on potential reasons for this finding, Gerlach (2007) constructs indicator variables from a word analysis of the ECB's assessment of economic conditions published in the ECB's monthly bulletin. He argues that the assessment in the official ECB report provides more accurate information about the Governing Council's view of the economy than external forecasts. He concludes from this analysis that the inflation increases that occurred over the sample were viewed to be temporary by the ECB and therefore the Governing Council did not react to them with interest rate changes. By contrast, changes in output were viewed by the ECB as an indicator of future inflation. Thus, it reacted strongly to them consistent with a forecast-based approach to monetary policy. The negative interest rate smoothing coefficient in Gerlach's ordered probit estimation has to be interpreted differently from the other studies that use ordinary least squares and instrumental variable regressions. It reflects that the interest rate is not adjusted every month. If the Governing Council decides to change the interest rate in one month the likelihood of another adjustment in the next month decreases.

Other studies on euro area interest rate rules have been conducted by Fourçans and Vranceanu (2004, 2007), Hayo and Hofmann (2006), Carstensen (2006) and Sauer and Sturm (2007). Further below, we will examine the role of euro area staff forecasts in explaining ECB interest rates. These forecasts have not been used in any of the studies cited above.

### **New empirical estimates**

Unfortunately, there are no publicly available ECB Governing Council projections for the euro area. However, as discussed in section 3 ECB staff projections for key euro area variables are published four times a year in the ECB's monthly bulletin. The forecasts in March and September are computed by the ECB's staff and the forecasts for June and December by Eurosystem staff including experts from the national central banks. These staff projections are available from December 2000 onwards. They are published as ranges reflecting uncertainty derived from past forecasting errors and cover HICP inflation, real GDP, private consumption, government consumption, gross fixed capital formation, exports and imports. We have used the ECB staff forecasts of inflation and real GDP growth to estimate forecast- vs outcome-based policy rules for the euro area similar to Orphanides (2001). Unfortunately, there is no data on output gap estimates or unemployment rates so as to estimate rules in the spirit of Orphanides and Wieland (2008). An important caveat is that we do not account for the ECB's declared practice of cross-checking the results of its economic outlook against medium-term monetary developments, the so-called monetary pillar of its strategy. Although Beck and Wieland (2007, 2008, 2009) have proposed a formal framework for including a cross-check against monetary trends in Taylor-style interest rate rules, a thorough empirical investigation is beyond

the present chapter.

We estimate forecast-based and outcome-based policy rules nested by the following specification:

$$i_t = \rho i_{t-1} + (1 - \rho)[\alpha + \beta E_t \pi_{t+h} + \gamma E_t y_{t+h}] + \epsilon_t. \quad (14)$$

In doing so, we consider four-quarter-ahead forecasts, ( $h = 4$ ), and nowcasts,  $h = 0$ , for inflation and output growth. As in the case of the FOMC projections, constant-horizon forecasts need be computed by appropriately averaging available ECB staff forecasts of different horizons.

Table 5: Computation of 4-quarter-ahead forecasts and nowcasts

	<u>Inflation</u>	
December	$\pi_{t+4 t} = \pi_{t+4 t}$	$\pi_{t t} = \pi_{t t}$
March	$\pi_{t+4 t} = 0.75\pi_{t+3 t} + 0.25\pi_{t+7 t}$	$\pi_{t t} = 0.25\pi_{t+3 t} + 0.75\pi_{t-1 t}$
June	$\pi_{t+4 t} = 0.5\pi_{t+2 t} + 0.5\pi_{t+6 t}$	$\pi_{t t} = 0.5\pi_{t+2 t} + 0.5\pi_{t-2 t}$
September	$\pi_{t+4 t} = 0.25\pi_{t+1 t} + 0.75\pi_{t+5 t}$	$\pi_{t t} = 0.75\pi_{t+1 t} + 0.25\pi_{t-3 t}$
	<u>Output Growth</u>	
December	$y_{t+4 t} = y_{t+4 t}$	$y_{t t} = y_{t t}$
March	$y_{t+4 t} = 0.75y_{t+3 t} + 0.25y_{t+7 t}$	$y_{t t} = 0.25y_{t+3 t} + 0.75y_{t-1 t}$
June	$y_{t+4 t} = 0.5y_{t+2 t} + 0.5y_{t+6 t}$	$y_{t t} = 0.5y_{t+2 t} + 0.5y_{t-2 t}$
September	$y_{t+4 t} = 0.25y_{t+1 t} + 0.75y_{t+5 t}$	$y_{t t} = 0.75y_{t+1 t} + 0.25y_{t-3 t}$

Notes: Forecast horizons correspond to the end quarter of expected average annual inflation and output growth rates.

ECB staff projections concern average annual percentage changes and are published for the previous year, the current year and the following year. The December projections also include a forecast for the year after next year. As a result, the horizon of published projections varies over time. For example, the forecast of average inflation next year that is published in December is a 4-quarter-ahead forecast and denoted as  $\pi_{t+4|t}$ . The forecast for next year published in September instead is a 5-quarter-ahead forecast,  $\pi_{t+5|t}$ . Constant-horizon forecasts may then be deduced as follows: (i) the projections published in December have the right forecast horizon; (ii) the projections published in September for next year ( $\pi_{t+5|t}$ ), and for the current current year,  $\pi_{t+1|t}$ , can be appropriately averaged to obtain a 4-quarter-ahead forecast,  $\pi_{t+4|t} = 0.25\pi_{t+1|t} + 0.75\pi_{t+5|t}$ . **Table 5** indicates how to derive the 4-quarter-ahead forecasts and the nowcasts needed for the regression analysis from the ECB staff forecasts published in the monthly bulletin in December, March, June and September.

The resulting parameter estimates for outcome- and forecast-based interest rate rules are reported in **Table 6**.<sup>27</sup> These estimates confirm earlier findings in the literature that a rule based on outcomes of inflation does not satisfy the Taylor principle. Unfortunately, the empirical fit of rules without interest

<sup>27</sup>The interest rate used in the estimation is the repo target rate.

rate smoothing is rather weak. Rules with interest-smoothing fit better, but much of this improvement is due to a high coefficient on the lagged interest rate between 0.8 and 0.9. Among the rules with interest rate smoothing, only the forecast-based rules satisfy the Taylor principle. Unfortunately the estimates are not very precise and the inflation response coefficient of the purely forecast-based policy rule is not significantly different from zero. However, both rules with inflation forecasts exhibit very good empirical fit as measured by the  $R^2$  and reasonable parameter values. By contrast, the parameters of the outcome-based rule are even less precisely estimated and the inflation coefficient is negative. These results suggest that rules with forecasts of inflation better describe ECB policy than rules with outcomes, but the findings are not as strong as in the case of the FOMC forecasts for the United States.

Table 6: Rules with ECB Forecasts of Inflation and GDP growth vs Outcomes: 2000-2010

	no interest smoothing			with interest smoothing		
	$\pi_t, y_t$	$\pi_{t+4}, y_{t+4}$	$\pi_{t+4}, y_t$	$\pi_t, y_t$	$\pi_{t+4}, y_{t+4}$	$\pi_{t+4}, y_t$
$\alpha$	1.54 (-1.86,3.13)	0.02 (-1.68,1.67)	1.09 (-0.14,2.48)	9.38 (-2.10,30.30)	-2.11 (-6.11,0.54)	-2.48 (-4.75,0.59)
$\beta$	0.28 (-0.55,1.48)	1.26 (-0.10,2.08)	0.58 (-0.34,1.18)	-4.64 (-17.42,1.19)	1.64 (-0.08,2.52)	2.48 (0.63,3.81)
$\gamma$	0.47 (0.16,0.94)	0.20 (-0.38,1.32)	0.43 (0.16,0.87)	2.07 (0.40,6.71)	0.93 (-0.04,2.93)	0.21 (-0.15,1.11)
$\rho$	0	0	0	0.89 (0.62,0.99)	0.81 (0.59,0.91)	0.78 (0.50,0.90)
$R^2$	0.63	0.46	0.65	0.94	0.95	0.94
$\bar{R}^2$	0.61	0.44	0.63	0.93	0.95	0.94

Notes: Parameters are estimated using nonlinear least squares for the case  $\rho \neq 0$ . 95% confidence bands are shown in brackets and are computed using a moving block bootstrap with 5000 repetitions and a block size of 4 observations.

Figure 3 displays the fitted values of the estimated forecast-based (dotted line) and outcome-based (dashed line) policy rules relative to the actual path of euro area short term interest rates (solid line, we use the repo rate target). Unfortunately, the empirical fit is not as impressive as in the case of the FOMC forecasts for the FOMC federal funds rate target in the United States. It is particularly poor in the case of the rules without interest-rate smoothing which show big deviations from actual policy decisions. By contrast, the rule with interest-rate smoothing follows actual interest rates very closely. However, given that the interest rate changes only slowly it is not so surprising that a rule with a high weight on last quarter's interest rate would seem to fit rather well. The graphical analysis does not bring forth big differences between forecast-based and outcome-based rules with interest rate smoothing.

Finally, we estimate again a specification that allows for mixtures of forecast- and outcome-based rules with the pure versions as limiting cases. It is defined as follows:

$$i_t = \rho i_{t-1} + (1 - \rho)[\alpha + \beta((1 - \phi_\pi)E_t \pi_t + \phi_\pi E_t \pi_{t+4}) + \gamma((1 - \phi_y)E_t y_t + \phi_y E_t y_{t+4})] + \epsilon_t, \quad (15)$$



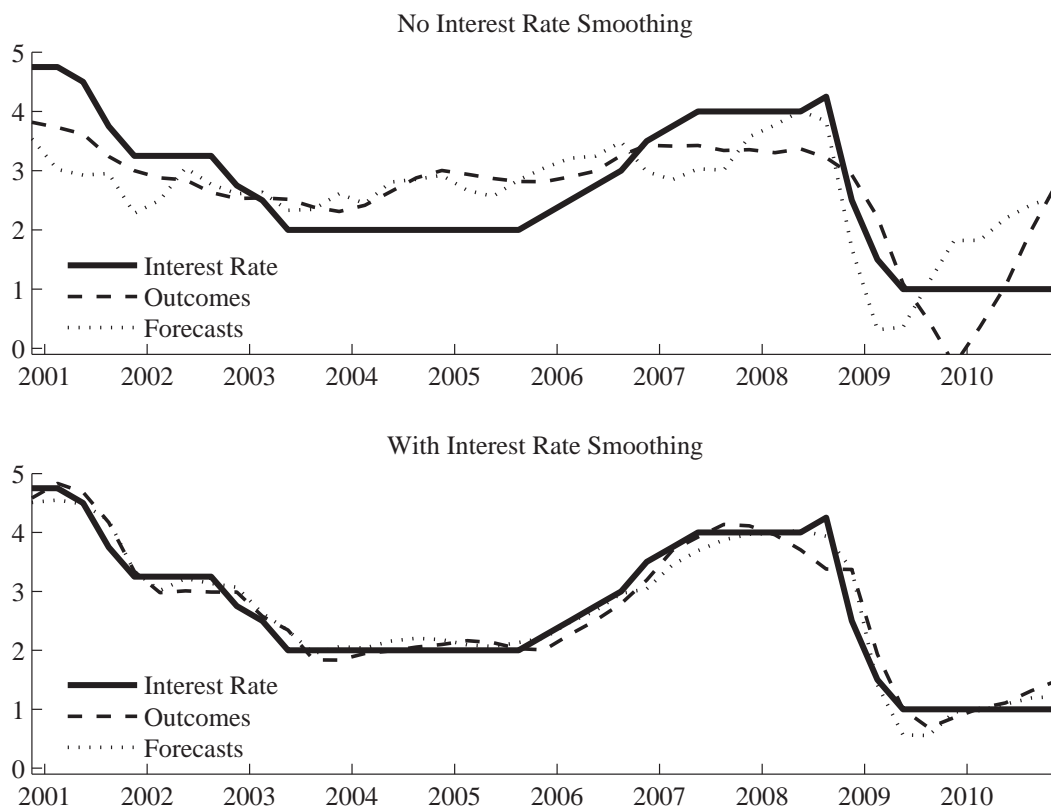


Figure 3: Outcome- and forecast-based monetary policy rules: euro area

The estimation results for the parameters governing the mixture of forecasts and outcomes are shown in **Table 7**. Again, the rules without interest rate smoothing exhibit poor empirical fit. Therefore we focus on the rules with interest rate smoothing. We find for all these specifications point estimates of  $\phi = \phi_{\pi} = \phi_y = 1$ . So, forecasts of inflation and output growth enter the policy rule, while outcomes do not play a role. However, due to the short sample most 95% confidence bands cover the whole range from 0 to 1. Only the confidence band for  $\phi_y$  excludes 0, but includes 1. It is clear that all estimates for the euro area have to be treated with caution because they are surrounded by high uncertainty due to the short sample. Additional data is needed. However, the point estimates suggest that forecasts of inflation and growth likely play a more important role for ECB decisions than recent nowcasts.

While the empirical literature reviewed in this section as well as our own estimation results provided overwhelming evidence that interest-rate setting at the Federal Reserve is conducted in a forward-looking manner and also delivered some indications that it might also be true for the ECB, these findings do not give an answer to the question whether forecast-based policy is desirable. Poole (1971) notes that desirability of forecast-based policy certainly depends on the accuracy of the forecasts. Thus, we will investigate different technical procedures for computing forecasts in the next section and then review the accuracy of such model-based forecasts together with expert forecasts

Table 7: Policy Reactions to Forecasts and Outcomes: 2000-2010

	no interest smoothing		with interest smoothing	
	$\phi_\pi = \phi_u$	$\phi_\pi \neq \phi_u$	$\phi_\pi = \phi_u$	$\phi_\pi \neq \phi_u$
$\phi$	0.44 (0.00,0.78)		1.00 (0.00,1.00)	
$\phi_\pi$		0.42 (0.00,1.00)		1.00 (0.00,1.00)
$\phi_y$		0.48 (0.00,1.00)		1.00 (0.12,1.00)
$R^2$	0.67	0.67	0.95	0.95
$\bar{R}^2$	0.63	0.63	0.95	0.95

Notes: Parameters are estimated using nonlinear least squares. The parameters  $\phi$ ,  $\phi_\pi$  and  $\phi_u$  are restricted to be in the range of 0 to 1. 95% confidence bands are shown in brackets and are computed using a moving block bootstrap with 5000 repetitions and a block size of 4 observations.

such as the Greenbook in section 5.6.

Furthermore, the simple framework for understanding the interaction of forecasts and policy presented previously in section 2.2 suggests that the relative performance of forecast- versus outcome-based rules also depend on the structure of the economy. We will return to this question in section 6.

## 5 Computing forecasts that account for the interaction with policy decisions

### 5.1 Forecasting models used at policy making institutions

#### Nonstructural time series models versus structural macroeconomic models

There are many purposes for producing forecasts at policy making institutions and their staff use a variety of forecasting methods. Covering the full range of motives and techniques is beyond this chapter. Furthermore, there are some important uses and techniques that we will not discuss in detail because they are very well covered in other chapters of this Handbook.

For example, we do not review the nowcasting techniques used at policy institutions. The term "nowcast" refers to the estimate of the current state of the economy. It constitutes a first important step in any forecasting exercise because macroeconomic data only become available with some time lag. To give an example, the first release of U.S. GDP is published late in the first month following the quarter it refers to and updated releases are published subsequently. Rather than relying only on GDP numbers from earlier quarters, forecasters typically use other available information that is related to economic activity to construct an estimate. Data used include monthly series of GDP components such as industrial production or surveys and financial variables such as stock prices that contain information

on perceptions regarding business conditions and economic growth. Typically, nowcasts are computed using non-structural time series models. They make it easier to incorporate high-frequency data. Current techniques include linear projections, bridge equations and dynamic factor models. For a more detailed review and applications of nowcasting techniques the reader is referred to the chapter on "Nowcasting with Daily Data" by Banbura et al. (2012).

Furthermore, simple non-structural time series models are widely used at policy institutions for predicting future developments in key variables of interest. They yield forecasts that are not easy to beat in terms of accuracy, in particular if they are initialized with efficient nowcasts. We do not discuss these forecasts in detail in this chapter because they cannot be used to assess the impact of planned changes in policy that are systematic in nature. In other words, such forecasting approaches are subject to the Lucas critique. Nonstructural models assume that market participants respond to policy as they did in the past. Thus, nonstructural forecasting techniques remain very useful for prediction in environments where policy will continue to be conducted in the same manner as in the past. For an exposition of different methods and a comparison of forecasting performance the reader is referred to the chapter by Faust and Wright (2012) on "Forecasting Inflation" in this Handbook. Recent comparisons of non-structural forecasting methods such as Bayesian VAR models with more sophisticated structural approaches can be found in Edge et al. (2010) and Wieland and Wolters (2011).

In the remainder of this section, we focus on the use of structural macroeconomic models for economic forecasting. These models incorporate explicit assumptions regarding the decision making of monetary and fiscal policy makers concerning variables such as government spending, taxes, transfers, central bank interest rates and central bank money. Furthermore, they provide characterizations of the decision making and expectations formation of households and firms that indicate how they will change their behavior in response to systematic changes in policy maker decisions. Thus, model equations and parameters have an economic interpretation that imposes particular parametric restrictions on the forecast relative to non-structural VAR models. In particular, we will use New Keynesian models which incorporate nominal rigidities such as staggered wage and price contracts that are important for analyzing short-run effects of monetary and fiscal policy.

We find it useful to distinguish between first- and second-generation New Keynesian models following Taylor and Wieland (2011) and Schmidt and Wieland (2012, in preparation). First-generation models are characterized by nominal rigidities, rational expectations and policy rules. Second generation New Keynesian models developed from the late 1990s onwards explicitly implement all the restrictions resulting from optimizing behavior of representative households and firms subject to concretely specified constraints. They are typically referred to as New Keynesian Dynamic Stochastic General Equilibrium (DSGE) models.

Small structural models typically consist of three to five equations representing key relationships such as a Phillips curve, an IS- or aggregate demand curve and a monetary policy rule. Examples of first-generation small-scale New Keynesian models are Fuhrer and Moore (1995a), Fuhrer and Moore (1995b), Fuhrer (1997) and Batini and Haldane (1999). Small-scale New Keynesian DSGE models are presented by Rotemberg and Woodford (1997), Goodfriend and King (1997) and Woodford

(2003).

### **Medium-size DSGE models used at policy institutions**

In recent years many policy institutions have built medium-size DSGE models that offer fairly detailed structural interpretations of the data. Such models are also used more and more as a central tool in the preparation of the main staff forecast at policy institutions.

For example, European Commission staff have been using a medium-size DSGE model with a detailed fiscal sector named QUEST for the analysis of euro area fiscal stimulus and consolidation policies (see Ratto et al. (2009) and Roeger and in 't Veld (2010)). Staff of the International Monetary Fund have developed a fairly large DSGE model, named GIMF, for the joint analysis of monetary and fiscal policies (see Freedman et al. (2010)). Interestingly, the European Central Bank has replaced its earlier, more traditional Area-Wide Model of Fagan et al. (2005) which featured largely backward-looking dynamics, with a New-Area-Wide Model (see Christoffel et al. (2008)) of the DSGE variety in the ECB staff forecasting process.<sup>28</sup> The Federal Reserve makes use of the FRB/EDO model of Edge et al. (2008),<sup>29</sup> though the FRB-US model still remains its principal model for policy analysis. DSGE models used at other central banks include the ToTEM model of the Bank of Canada (Murchison and Rennison, 2006; Fenton and Murchison, 2006) and the RAMSES model used at the Swedish Riksbank (Adolfson et al., 2007b, 2008). All these models build on the medium-size DSGE model of Christiano et al. (2005). Christiano et al extended the simple New-Keynesian DSGE model and showed that such a medium-size DSGE model can match the VAR-based estimate of a monetary impulse response function. Typically, these models are estimated instead with Bayesian estimation methods as proposed and exemplified by Smets and Wouters (2003, 2007). In this manner they are able to explain the dynamics of a large number of macroeconomic time series.

An appealing feature of DSGE models is that they implement all restrictions arising from optimizing behavior of households and firms subject to clearly specified constraints. Thereby they go further in addressing the Lucas critique and offer useful input for fiscal and monetary policy making. DSGE models are less flexible than first-generation New Keynesian models in terms of freely introducing additional lags of endogenous variables to capture empirical dynamics. This lack of flexibility is typically made up for by introducing unrestricted serial correlation in the economic shock processes. The economic shocks themselves are typically derived within the context of microeconomic foundation and more meaningful than shocks that are simply added to behavioral equations as in some of the earlier-generation New Keynesian models. However, the unrestricted

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<sup>28</sup>In addition, the model of Christiano et al. (2008), which includes a more detailed financial sector also plays an important role. The use of both models at the ECB is described in Smets et al. (2010)

<sup>29</sup>The FRB-EDO features two production sectors, which differ with respect to the pace of technological progress. This structure can capture the different growth rates and relative prices observed in the data. Accordingly, the expenditure side is disaggregated as well. It is divided into business investment and three categories of household expenditure: consumption of non-durables and services, investment in durable goods and residential investment. The model is able to capture different cyclical properties in these four expenditure categories. The model is estimated using Bayesian techniques on eleven time series.

serial correlation of these shocks is similarly ad-hoc as lags of endogenous variables in the earlier models. Even so, this feature has quickly been popularized in policy applications. The estimated degree of serial correlation importantly contributes to the forecasting power of the DSGE models. Several studies have shown that estimated DSGE models can generate forecasts of reasonable accuracy (Smets and Wouters, 2004; Adolfson et al., 2007a; Smets and Wouters, 2007; Edge et al., 2010; Wang, 2009; Christoffel et al., 2010; Wieland and Wolters, 2011).

### **Large-scale macroeconomic models used at policy institutions**

Many policy making institutions use even larger-scale models that contain many additional variables of interest to those institutions. The International Monetary Fund and the European Commission, for example, have large multi-country models at their disposal. Another well known example is the FRB/US model that has been used at the Federal Reserve since 1996 and contains many more data series for the U.S. economy than standard DSGE models. Typically, these models are not fully-fledged DSGE models. They may contain many additional ad-hoc specifications as in the earlier-generation New Keynesian models.

The FRB/US models has been documented in Brayton and Tinsley (1996) and Reifschneider et al. (1999). Individual equations or equation blocks are based on economic theory and inspired by the optimization problems of households and firms. However, they do not systematically enforce the restrictions implied by optimizing behavior subject to constraints as is done in DSGE models. The model aims to provide a good balance between data fit and economic theory. For example, the lag structure of adjustment cost processes is chosen to provide a good fit to the data and therefore polynomial adjustment processes are added to most equations (see Tinsley, 1993, for more details). While the equations can be interpreted structurally, the addition of polynomial adjustment cost processes makes this more difficult (Taylor, 1997). It contains—depending on the specific version—50 stochastic equations that describe the economic behavior of different agents and 300 identities that define additional variables. By contrast, the FRB/EDO model—a DSGE model that has been developed at the Fed—contains only 11 observable and about 60 equations where most variables are treated as unobservable and are determined via the application of the Kalman Filter to the state space representation of the model.

One of the advantages of large econometric models is that they contain all important macroeconomic aggregates. For example, FRB/US model breaks down aggregate demand into private consumption, fixed investment, inventory investment, net exports and government purchases. These broad categories are disaggregated even further. For example, spending on fixed investment is separated into equipment, nonresidential structures and residential construction. Government spending is divided into six sub-components. Aggregate supply is also disaggregated. Potential output is modeled as a function of the labor force, crude energy use, and a composite capital stock, using a three-factor Cobb-Douglas production technology. While variables are assumed to move gradually to eliminate deviations from equilibrium values, they also respond to expected future equilibrium values. Expectations are also important in the financial sector. The long-term interest rate equals expected future short

rates and a term premium. Real stock prices equal discounted expected future dividend payments. To estimate the model expectations are assumed to be formed by small VARs. However, for simulations one can choose whether to use the VAR-based expectations or a fully rational expectations based version.

The forecasting accuracy of the FRB/US model and the Fed's DSGE model (FRB/EDO) has been compared in Edge et al. (2010). Overall, the FRB/EDO model yields more precise forecasts, probably due to its more parsimonious parametrization. However, the forecasts from both models regarding key variables such as inflation are less accurate than the Greenbook forecasts. The superiority of the Greenbook forecasts may be due to the judgement used and information gleaned from other sources than the data series used by the models.

In the following, we will show how to employ structural models for identifying the sources of predicted dynamics of key macroeconomic variables and for interpreting forecasts. Since policy makers frequently request forecasts that are conditioned on particular plans for certain policy instruments, we will review techniques for computing such conditional forecasts. In doing so we show how to include judgment in model-based forecasts. Furthermore, we compare forecasts from smaller and larger models with other available forecasts and assess forecast accuracy. For a detailed technical presentation of the steps that need to be taken to produce forecasts with estimated structural macroeconomic models we refer the reader to the chapter on "DSGE Model-Based Forecasting" by Del Negro and Schorfheide (2012) in this Handbook. Furthermore, we would like to make the reader aware of a new model database and computational platform that makes small- medium- and even large-scale models available to the public and allows individual researchers to evaluate models developed and used at policy institutions (see Wieland et al. (2012) and [www.macromodelbase.com](http://www.macromodelbase.com)).

## **5.2 Forecasts from a small structural model: IMF's small quarterly projection model**

We start by deriving forecasts from a particular small-scale structural New Keynesian model. The IMF's small quarterly projection model of the U.S. economy (Carabenciov et al., 2008) belongs to the first generation of New-Keynesian models. It is a closed economy model that captures the dynamics of output, inflation, a short term interest rate and the unemployment rate. According to the authors it offers a simple but plausible structure suited to forecasting and policy analysis at policy institutions. The main policy instrument considered is the central bank interest rate. It does not include fiscal variables. Similar models calibrated for different countries are currently used at several country desks at the IMF to help structure the dialogue with member countries.<sup>30</sup>

### **The model**

The core of the model consists of an IS-equation, a Phillips curve, a monetary policy rule and a

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<sup>30</sup>See p. 7 of (Carabenciov et al., 2008) for more references.

version of Okun's law relating unemployment to the output gap:

$$y_t = \beta_1 y_{t-1} + \beta_2 E_t y_{t+1} - \beta_3 (i_t - E_t \pi_{t+1}) - \theta \eta_t + \epsilon_t^y, \quad (16)$$

$$\pi_t = \lambda_1 E_t \tilde{\pi}_{t+4} + (1 - \lambda_1) \tilde{\pi}_{t-1} + \lambda_2 y_{t-1} - \epsilon_t^\pi, \quad (17)$$

$$i_t = (1 - \gamma_1) [\gamma_2 (E_t \tilde{\pi}_{t+3}) + \gamma_3 y_t] + \gamma_1 i_{t-1} + \epsilon_t^i, \quad (18)$$

$$u_t = \alpha_1 u_{t-1} + \alpha_2 y_t + \epsilon_t^u, \quad (19)$$

$$BLT_t = \bar{BLT}_t - k E_t y_{t+4} + \epsilon_t^{BLT}, \quad (20)$$

$$\eta_t = \sum_{i=1}^9 k_i \epsilon_{t-i}^{BLT}. \quad (21)$$

All variables are expressed in terms of deviations from equilibrium values. Certain equilibrium values are modeled as stochastic processes (not shown), for example, potential output is driven by permanent level shocks as well as highly persistent shocks to its growth rate. Thus,  $y_t$ , which denotes output, is the deviation of the level of output from potential, that is the output gap.

The IS equation (16) relates the output gap to one lag and one lead of itself, the real interest rate,  $i_t - E_t \pi_{t+1}$ , bank lending conditions indicated by  $\eta_t$ , and a demand shock,  $\epsilon_t^y$ . The Phillips curve equation (17) relates the quarterly inflation rate  $\pi_t$ , to the past and expected future four-quarter moving average of inflation (i.e. the year-on-year rate),  $\tilde{\pi}_t$ , the lagged output gap and a cost-push shock,  $\epsilon_t^\pi$ . The interest rate rule (18) describes the determination of the short-term nominal interest rate  $i_t$  in response to the lagged rate, the output gap and deviations of inflation from target (normalized at zero) as well as a monetary policy shock  $\epsilon_t^i$ . The equation for unemployment (19) is a version of Okun's law, linking the deviation of the unemployment rate from the equilibrium unemployment rate,  $u_t$ , to the output gap.

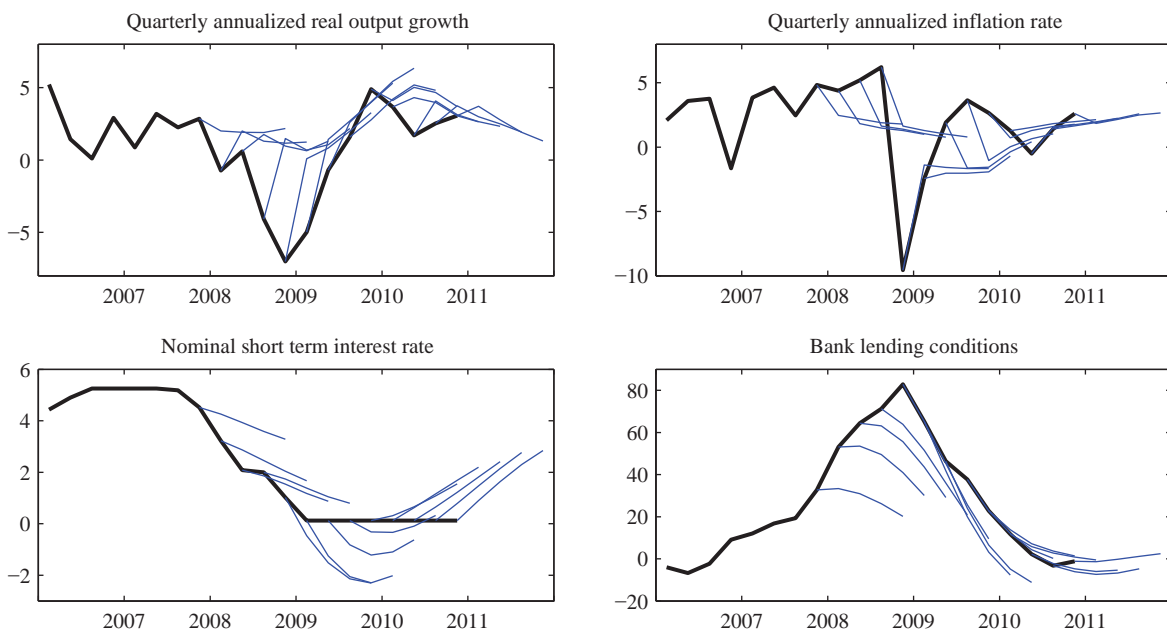
The model exhibits inertia in output and inflation dynamics and short-run real effects on monetary policy. In the long run, monetary policy only determines inflation. A novel feature of the model is the inclusion of linkages between financial intermediation and business cycle dynamics. Equations (20) and (21) serve to measure the degree of bank lending tightness,  $BLT_t$ , that impacts on aggregate demand. The corresponding empirical measure is obtained from survey answers regarding financial conditions from the Federal Reserve Board's quarterly Senior Loan Officer Opinion Survey on Bank Lending Practices. Banks are assumed to adjust their lending practices around an equilibrium value,  $\bar{BLT}_t$ , depending on their expectations about the real economy four quarters ahead and a financial shock  $\epsilon_t^{BLT}$ . The equilibrium value of bank lending conditions follows a random walk. Banks are assumed to ease their lending conditions during economic upturns and tighten them during downturns. To link bank lending conditions to the real economy the lagged 8-quarter moving average of the financial shocks,  $\eta_t$ , enters the aggregate demand equation.

## Forecasts

We have re-estimated the IMF projection model using U.S. data for real GDP, the CPI, the federal funds rate, the unemployment rate and bank lending conditions (BLT) from 1994Q1 to 2007Q4. Our

parameter estimates are very similar to those of Carabenciov et al. (2008). We have computed forecasts for all variables in the model including the unobservable equilibrium or natural values. The first set of forecasts uses information up to 2008Q1. Then, we add data realizations sequentially and compute a set of forecasts up to four quarters ahead. We focus on point forecasts disregarding potential data revisions.

**Figure 4** compares the forecasts (thin blue lines) for quarterly real GDP growth, quarterly CPI inflation, the federal funds rate and bank lending conditions to subsequent data realizations (thick black lines). Despite its flexible formulation with various lags and permanent as well as temporary shocks, the IMF model has difficulties predicting output growth during the financial crisis and recession. Note, this is not a particular shortcoming of structural model forecasts but also applies to non-structural time series models and professional forecasts available from surveys. Perhaps, it is somewhat disappointing that the inclusion of data on bank lending tightness in the model does not help much in improving forecasts of the recession triggered by the financial crisis. On the positive side, forecasts are quite accurate from 2009Q1 onwards and capture the initial recovery process surprisingly well. The initial recovery during 2009 and 2010 is predicted to be followed in the next year by growth rates broadly in line with average growth, which is estimated to be 2.6% in the sample.



**Figure 4:** Quarterly GDP growth, CPI inflation, federal funds rates and bank lending conditions: Data (thick black line) and forecasts (thin blue lines)

The model correctly predicts inflation to fall during the recession, but it fails to capture the extreme decline in the fourth quarter of 2008. From 2009 onwards inflation projections are fairly precise. The projections of the federal funds rate explain why output growth estimates during the recovery turn out too optimistic. The model forecast does not enforce the zero bound on nominal interest rates. It allows rates to turn negative thereby incorporating too much stimulus to output. Imposing the



zero-interest-floor on nominal interest rates would have resulted in less optimistic output forecasts. We will demonstrate a simple procedure for adjusting forecasts to take into account the zero-lower-bound in section 5.4. We will discuss forecast accuracy during recessions in more detail in section 5.6.

### Unobservable variables and forecast interpretation

The structural model includes unobservable variables such as potential output growth that help users interpret the economic forces driving the forecast. For example, the longer-term impact of the financial crisis on GDP may be judged by forecasts of the level and growth rate of potential output.

**Figure 5** displays actual versus potential output and actual versus natural unemployment rates over the whole sample together with an out-of-sample forecast for 2011 and 2012. Potential output

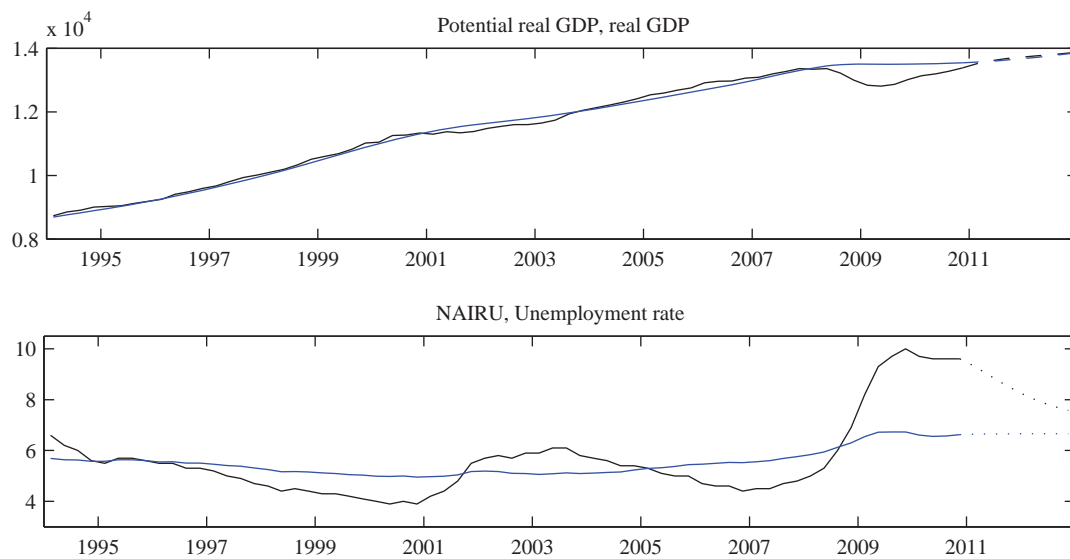


Figure 5: Actual vs potential GDP and actual vs natural unemployment rate.

growth is first estimated to slow down around 2001 followed by a more severe slowdown in 2008. The growth rate of potential GDP is projected at about 0.5% at the end of the sample. While the output gap (not shown) is still in negative territory in 2010Q4, it is projected to turn slightly positive in 2011, and remain near zero throughout 2012. Thus, it indicates no inflationary pressure from aggregate demand. Accordingly, year-on-year output growth is projected to slow down in 2012 towards 1.5 percent. This forecast is about 1 percentage point lower than the forecast we have obtained from non-structural time series models (not shown).

Relative to the estimated changes in potential output, the up-ward trend in the natural unemployment rate or NAIRU seems less extreme. It is projected at 7 percent by 2011. Thus, it explains only a smaller part of the increase in the unemployment rate. The model predicts unemployment to decline towards 8.40 percent by the end of 2011, which is slightly below the forecast we obtained from non-structural models (not shown).

This example shows that a structural model can help interpreting the forecast by projecting

unobservable equilibrium-related concepts such as potential output and the natural rate. Of course, one might ask, what are the economics behind the sizeable impact on potential growth. While the assumed non-stationary stochastic process adds flexibility to the model, the model remains silent on the question to what extent the slowdown is due to lower capital utilization, a period of reduced investment or a preference shift towards leisure. Answers to such questions could be obtained from the type of medium-size DSGE model we will discuss in the next subsection.

### **Structural shocks and forecast interpretation**

Another unobservable element of structural models is given by the economic shocks. Structural shocks differ from estimation residuals. They require identification via parametric restrictions. Furthermore, in models with forward-looking terms identifying structural shocks requires computing the expectation of future variables so as to separate out the forecast error. Structural shocks may be interpreted as meaningful economic disturbances. Of course, the extent of useful interpretation depends on the economic foundations for the parametric restrictions in the model. Since the IMF projection model is not strictly micro-founded some of these shocks have little concrete interpretation. Even so, distinguishing aggregate demand shocks in the IS curve from cost-push shocks in the Phillips curve and long-run supply shocks to potential output, helps understanding whether inflation is primarily driven by demand-pull factors, short-run cost-push shocks or productivity changes that may be related to technological improvements.

**Figure 6** display the estimated series of structural shocks. The sequence of negative demand shocks between 2008 and 2010 indicates that according to this model an unexpected shortfall of demand (i.e. the shocks) caused an unexpected decline in GDP. Furthermore, the sequence of positive monetary policy shocks in 2009 indicates that interest rates were higher than expected based on the policy rule, and therefore represented an additional cause for an unexpected decline in GDP. The sequence of negative shocks to potential GDP growth and the sequence of positive shocks to bank lending tightness also contribute to the unexpected drop in GDP.

In sum, these shocks reflect again the inability of the model to forecast the recession, but they help point to sources of the unexpected shortfall. The forecasting power of the model arises from predictable endogenous dynamics such as lags of output, inflation or interest rates, and from predictable exogenous dynamics such as the persistence of the bank lending tightness shocks. The sequence of positive monetary policy shocks in 2009 may be due to the omission of the zero bound. Including this constraint may therefore improve the forecasting performance.

The large positive cost-push shock in 2008Q4 reflects the failure of forecasting the decline in inflation since this shock enters the Phillips curve negatively. According to this model the drop in inflation is largely due to a sudden decline in costs and to a lesser extent to the disinflationary impact of a shortfall of demand. Thus, without using data on energy prices the model indicates that the decline of energy costs was largely behind the drop in inflation in 2008Q4. A sequence of positive shocks to unemployment in 2010 represents a source of unexpectedly high unemployment at the end of the recession according to this model.

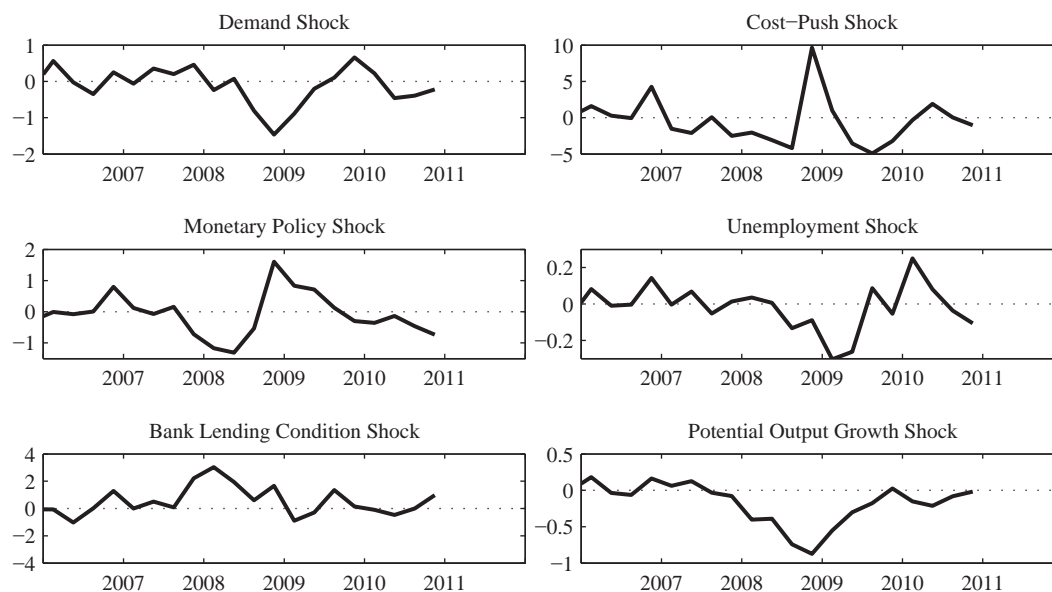


Figure 6: Estimated shocks in the IMF's quarterly projection model.

Finally, one can explore the parameter estimates of the model to gauge the importance of different channels of influence in determining the forecast. One could also re-estimate the model for each forecast to investigate whether certain parameter values change a lot over time and thus spot structural changes. Here, we only point out the parameters governing the shock process to potential output. The estimates show that each quarter potential output growth equals 0.93 times the previous potential output growth rate plus 0.07 times steady state growth. It thus takes a long time until potential output growth returns back to steady state. On the other hand, the estimation results show that the estimated variance of the growth rate of potential output is relatively high. In **Figure 6** the lower right panel shows shocks to the potential output growth rate. A series of highly negative shocks led to the current extremely low estimates of potential output growth. Given the high variance of this shock series potential output could quickly adjust back to higher equilibrium growth rates once actual output growth increases.

### 5.3 Forecasts from a medium-scale New-Keynesian DSGE model for monetary and fiscal policy analysis

#### Brief Model Description

In the following, we will produce and interpret forecasts using a medium-scale DSGE model estimated in Cogan et al. (2010). Cogan et al. extended the Smets and Wouters (2007) model of the U.S. economy by introducing a share of households that consume current income. As a consequence, the model does not anymore exhibit Ricardian equivalence. The path of taxes and debt is not irrelevant. Tax and debt dynamics are modeled explicitly. Such an extension was proposed by Galí and Lopez-Salido (2007) in the context of a small New Keynesian model in order to better understand the

consequences of fiscal policy, specifically changes in government purchases. Cogan et al. (2010) use this model to analyze the interaction of monetary policy and the U.S. ARRA fiscal stimulus at interest rates near the zero-lower bound. In the following, we refer to this model as the CCTW-SW model.

The CCTW-SW model contains a large number of frictions and structural shocks. Physical capital is included in the production function and capital formation is endogenous. Labor supply is modeled explicitly. Nominal frictions include sticky prices and wages and inflation and wage indexation. Real frictions include consumption habit formation, investment adjustment costs and variable capital utilization. Utility is nonseparable in consumption and leisure. There exist fixed costs in production. The aggregator by Kimball (1995) is used which implies a non-constant elasticity of demand. The model includes equations for consumption, investment, price and wage setting as well as several identities. It contains seven structural shocks and it is fit to seven time series. Among the shocks are, total factor productivity, risk premium, investment-specific technology, wage mark-up, price mark-up, government spending and a monetary policy shock. All shock processes are serially correlated. Cogan et al. (2010) estimate a posterior mean of 26.5% of rule-of-thumb consumers and feedback equations for taxes that ensure a return to the steady-state debt to GDP ratio. A complete list and description of the equations is contained in appendix A.

## Forecasts

We have re-estimated the model with data from 1965Q3 to 2007Q4. On this basis, we have computed forecasts for all variables in the model including unobservable concepts like potential output and the natural rate of interest. We compute a sequence of forecasts starting in 2008Q1 by adding subsequent data realizations sequentially up to the final set of forecasts as of 2011Q1. Again, we focus on point forecasts.<sup>31</sup>

**Figure 7** displays forecasts for quarterly real output growth, consumption, investment, quarterly inflation<sup>32</sup> (annualized) and the federal funds rate.

The output growth forecasts are roughly similar to those computed with the small structural IMF

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<sup>31</sup>We neglect that data revisions and current quarter observations are not observable when computing a forecast. We take the same data series and transform them in the same way as in Smets and Wouters (2007) with one exception: the hours per capita series. This series is non-stationary (see e.g. Chang et al., 2007) and it is influenced by low frequency movements in government employment, schooling and the aging of the population that cannot be captured by a simple DSGE models. Thus, we follow Francis and Ramey (2009) and remove these trends by computing deviations of the hours per capita series using the HP filter with a weight of 16000 (compared to the standard weight of 1600 used for business-cycle frequency de-trending). Without this additional data treatment the Smets & Wouters model yields an unreasonable output gap that is largely negative for most parts of the sample. For each forecast we apply the HP-Filter only until the forecast starting point to prevent that this two-sided filter uses information about data points in the future.

<sup>32</sup>The inflation rate is not directly comparable to the IMF model because the IMF model uses the CPI inflation rate, while the Smets & Wouters model uses the GDP deflator. To solve the problem that DSGE models contain only a very limited set of variables Schorfheide et al. (2010) propose to use auxiliary equations to link non-modeled variables to the state variables in the model. Predictions for the non-core variables are obtained by applying their measurement equations to DSGE model-generated forecasts of the state variables. In this way one can base forecasts of these non-core variables (including different definitions of inflation) on the structural representation of the model.

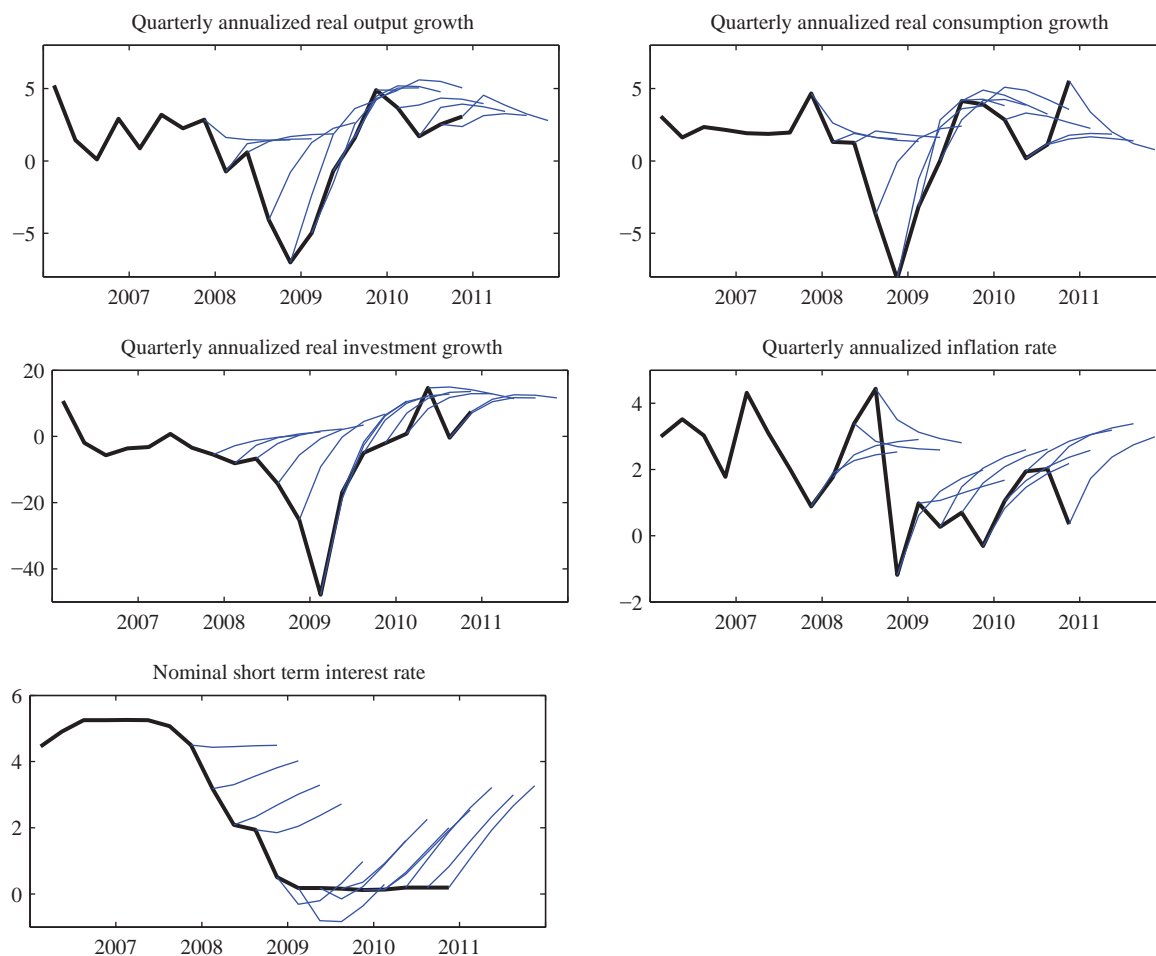


Figure 7: Real GDP growth, consumption growth, investment growth, inflation and the nominal interest rate: Actual (black line) and forecasts (blue lines).

model in the previous section. There is a strong comovement of output, consumption and investment. The fluctuations of investment growth are much larger than those of consumption growth. The model cannot predict the large recession in 2008/2009 and tends to predict a relatively quick return to the balanced growth path in 2008Q3 while the recession actually deepened. Once the turning point has been reached in 2008Q4 the recovery is predicted quite well. Forecasts are quite accurate from 2009 onwards even though growth turned out to be somewhat lower in 2010 than predicted by the model.

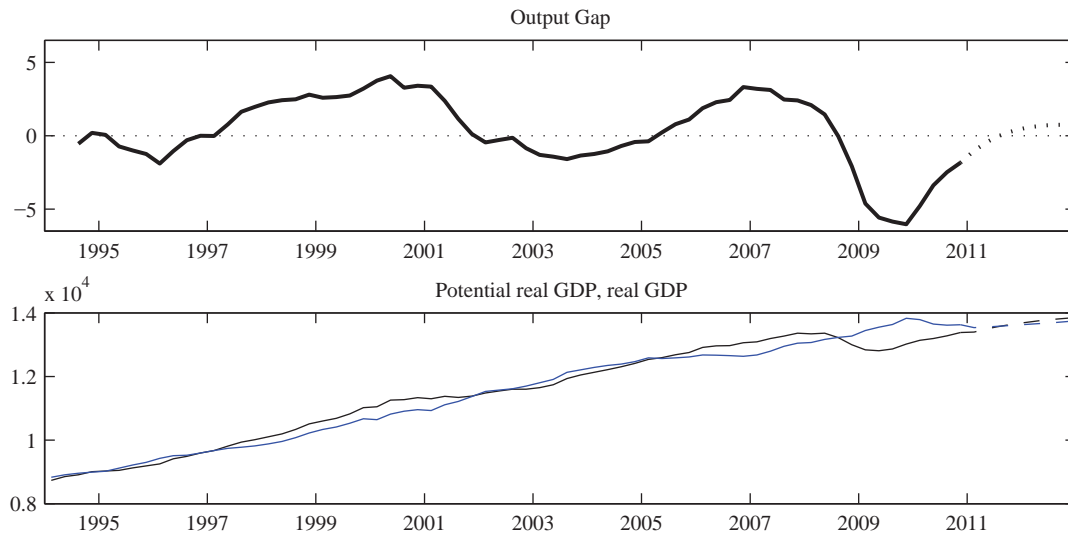
The forecast for investment growth is very persistent. Investment is predicted slightly below 12 percent for 2011. Afterwards, it is expected to decrease slowly to a substantially lower steady state rate of about 2.4 percent, similar to GDP.<sup>33</sup>

The model cannot predict the spikes in inflation in 2008 and overpredicts inflation from 2009 to the end of 2010. The steady-state inflation rate is estimated to be 2.5% and thus higher than the most

<sup>33</sup>The high degree of persistence may be explained by the discrepancy between the average output growth rate and the much higher average investment growth rate observed in the data. The model enforces the same steady state value and introduces persistence in investment to fit actual data series.

recent data observation. Accordingly, the model predicts increasing inflation rates reaching 1.8% in 2011 and 3% in 2012.

Federal funds rate forecasts violate the zero-lower bound in 2009. The difference of the model relative to the actual funds rate setting at 25 basis points manifests itself also in adverse monetary policy shocks. In contrast to the IMF model the steady state interest rate is fixed and the interest rate forecast always predicts a return to the steady state.



**Figure 8:** The figure shows the model consistent output gap and the level of real GDP and real potential GDP. Values after 2011 are forecasts. While real GDP is observable, the output gap and potential output are derived via the Kalman Filter.

**Figure 8** shows actual real GDP relative to potential and the resulting output gap estimate. Values after 2011 are forecasts. Between 2005 and 2008 the output gap is positive. In 2009 it turns negative because real GDP declined, while potential output still increased. In 2010 the output gap comes close to zero as real GDP grew again and potential output declined. The forecast for the output gap is slightly above zero as real GDP is predicted to grow somewhat faster than potential GDP. In this model potential GDP and the output gap have a clear structural interpretation. While in the previous small structural model potential GDP was modeled as a trend, it is defined in the DSGE model as the level of output and expenditure that would be realized in the absence of price and wage rigidities and price and wage mark-up shocks.

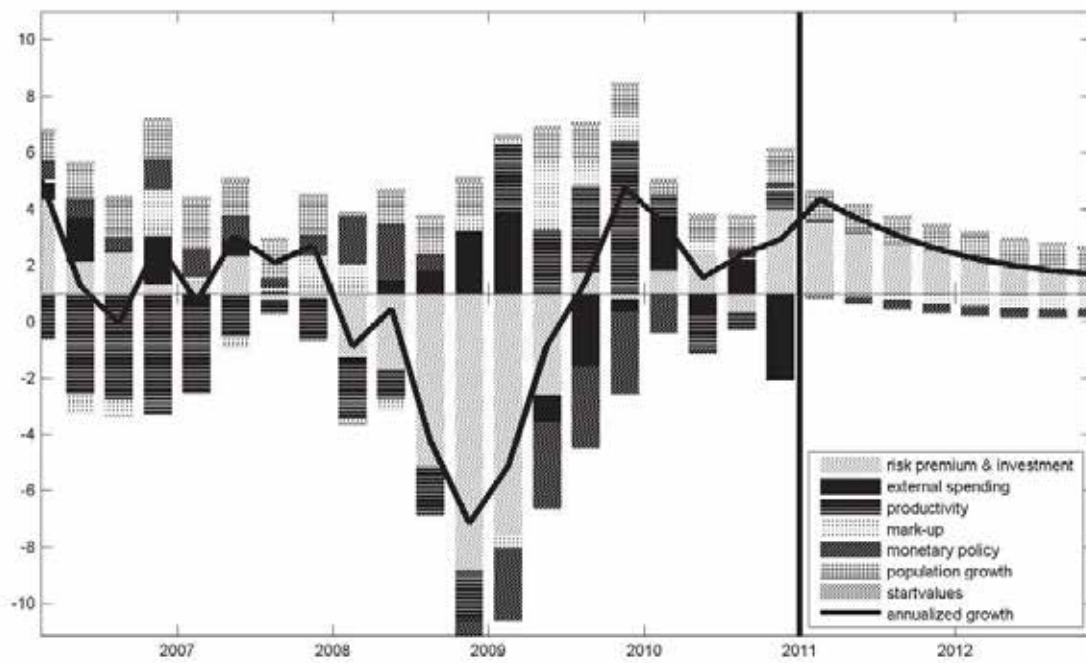
### Decomposition in structural shocks for forecast interpretation

To analyze which shocks played an important role during the financial crisis and recession, and to investigate which of them have a lasting impact over the forecast period, we derive a decomposition. Using the moving average representation of the model solution, we evaluate how much each type of shock contributes to a particular variable at each point in time over the sample and forecast periods. The model contains seven shocks: a risk premium shock, investment-specific technology shock, general technology shock, monetary policy shock and price and wage mark-up shocks. **Figure 9** displays

the decomposition of quarterly output growth (annualized). The bars for each period summarize the contributions of all shocks to output growth, some of them positive some negative. The areas with different textures identify the size of the contribution of each type of shock.

In addition to the shocks, the label of the chart refers to two more contributions to growth termed "starting values" and "population growth". The bars labeled starting values appear because data is not available for an infinite past history, and therefore shock realizations cannot be recovered from an infinite past. Thus, the "starting values" bar indicates the impact of the initial conditions. Their effect is negligible over the period shown in **Figure 9**.

DSGE models are usually defined in per capita terms. However, policy makers are more interested in aggregate growth rates. Therefore, the black solid-line indicates overall real GDP growth rather than per capita growth. Consequently, part of the GDP growth is due to population growth. This contribution is indicated by the "population growth" bars. As population growth is not defined in the model, we simply assume that the population continues to grow at the rate observed in 2009 and 2010. The horizontal axis indicates the steady-state per capita growth rate. For long-run forecasts the impact of the shocks will disappear and per capita growth will converge to this estimate of steady state growth.



**Figure 9:** The figure shows a historical decomposition of annualized quarterly real output growth. The vertical line in 2011 indicates that values afterwards are forecasts. The black line show the output growth rate and the bars show the contribution of the different shocks, the population growth rate and initial values. The sum of the bars equals the output growth rate.

The positive and negative contributions from shocks, population growth and initial conditions sum up to the actual output growth rate (black line) over the sample period and to the predicted output growth rate over the forecast period. Interestingly, the deep recession of 2008 and 2009 is largely attributed to the combination of substantial (positive) risk premium shocks and negative investment shocks. The contribution of these two types of shocks is lumped in the left shaded area of the contribution bars.

In other words, the recession, which was not predicted by the model, is explained as being due to a sequence of unexpectedly high risk premia realizations together with unexpected shortfalls of investment demand. To the extent these shocks are estimated to persist, they also help predict future growth. Thus, even though the model does not utilize financial data other than federal funds rates, nor integrate asset prices and banking risk, it correctly points towards financial conditions and lack of investment as the cause of the recession. The risk premium shock is simply modeled as an exogenous premium in the return to bonds in the consumption equation, while the investment shock is modeled as a shock to the price of investment goods relative to consumption goods.

The other shocks have largely offsetting impacts on growth during the recession. The exogenous spending shock contributes positively to growth consistent with the observed improvement of the current account during this period. Throughout 2009 we observe contractionary monetary policy shocks. They arise because actual policy is constrained at the zero bound, while funds rate expectations turn negative throughout 2009 as prescribed by the policy rule's response to output and inflation conditions.

Over the forecast period from 2011 onwards, GDP growth returns to steady state as the impact of positive demand shocks dissipates. The main reason for the forecast staying above average growth over the forecast period are the investment-specific technology shocks. In the medium term the price-markup shocks reduce the output growth forecast somewhat. They reflect an exogenous price increase that causes inflation and depresses output.

## **5.4 Conditioning forecasts on specific future policy decisions**

### **Types of conditioning assumptions**

Staff forecasts at policy institutions often form an important basis for discussions among decision makers. Frequently, they also request that staff forecasts be conditioned on a particular hypothetical path for future policy. Depending on the resulting forecasts, policy makers can then consider whether and how to change the policy instrument they are charged to use relative to the assumed baseline. There are a number of different underlying assumptions that may be used for generating such policy-conditioned forecasts: (i) unchanged policy; (ii) market-based expectations; (iii) a decision by policy makers on a preferred anticipated policy path; or (iv) an estimated or preferred policy rule.

(i) *Unchanged policy.* For example, the baseline budget forecast of the U.S. Congressional Budget Office is always based on existing laws and regulations. Similarly, many central banks use staff forecasts that are based on a constant interest rate path. Such a simple benchmark path may be



considered useful by members of a decision making committee for they can state their personal opinions relative to a seemingly purely technical benchmark. It should be understood, however, that a forecast based on unchanged fiscal or monetary policy is usually not the best possible forecast. It may not even be consistent with long-run stability. For example, the forecast of a particular budget deficit under existing laws and regulations may imply that government debt is unsustainable. Similarly, a constant central bank interest rate path may imply explosive dynamics. In fact, in rational expectations models it is essential for the existence of a short-run equilibrium that policy rates eventually adjust in an endogenous manner.

(ii) *Market-based expectations.* An alternative conditioning assumption is given by market-based expectations of the relevant policy variable. These expectations may reflect market participants perceptions of the policy rule that best describes the systematic, predictable component of policy makers' decision making. An assumed future policy path based on market expectations avoids the lack of plausibility of the unchanged policy assumption. It also avoids difficulties and commitment issues arising in the construction of a path that reflects policy makers' expectations. However, market expectations may not be conditioned on a sufficiently stabilizing policy. Including this assumption directly in public policy maker forecasts, which then determine policy decisions, could mean that market expectations feed back on themselves. This may be stabilizing or not, but certainly complicates communication regarding the forecast.

(iii) *Decision on preferred anticipated policy path.* A more consistent approach would be to ask policy makers first to decide on an anticipated path for the policy variable and then use this path to create a forecast. Whether or not such consistency is needed or even helpful for decision making is likely to depend on the particular role of the forecast in the policy making process. For example, if there is a debate in parliament about the likely budgetary impacts of certain fiscal initiatives it would appear perfectly suitable for the staff of the budget office to supply different forecasts conditioned on each policy proposal that is being debated. A different matter may be the forecast of central bank staff that plays a key role in central bank communication to the public as practiced primarily at inflation targeting central banks. In this case, it may be quite important to present the best possible forecast to the public. As such it should be conditioned on the most likely policy path that can be constructed based on the knowledge of decision maker preferences. It may be difficult to organize such a process but it is likely to improve communication with the public.

(iv) *Policy rule.* Finally, another possibility would be to condition the forecast on a policy rule that captures the policymaker's past responses to important macroeconomic variables or a new rule that matches policymakers' preferences. Examples would be central bank interest rate rules such as those estimated in section 4 of this chapter. Similarly, forecasts used for fiscal policy purposes could be based on particular feedback rules for government purchases, transfers or tax rates. However, policy makers might not be inclined to assign a particular rule such a prominent place in their deliberations.

Furthermore, if members of a decision making committee disagree about specific policy objectives they will also disagree on the appropriate policy rules.

### Experience with different conditioning assumptions at central banks

A detailed discussion of the practices at central banks is available from Goodhart (2009). **Table 8** lists conditioning assumptions used by several central banks.

Table 8: Conditioning assumptions of different central banks

constant path	market based expectations	policy committee based expectations
US (most of the time)		
UK (1992-2004)	UK (since 2004)	
Sweden (until 2007)		Sweden (since 2007)
euro area (until 2006Q1)	euro area (since 2006Q2)	
		Norway (since 2006)
		New Zealand

Central banks have primarily used the first three approaches from the above list. Thus, they have used a constant interest rate path based on the latest interest rate level; expected future short term interest rates implied by the yield curve, and a path that explicitly corresponds to the expectations of the monetary policy committee for future interest rates.

The choice between these three conditioning assumptions also appears to depend on whether the conditional forecast is only used internally or whether it is used to communicate policy to the public. While conditioning on a constant interest rate path might be a useful input in policy committee deliberations, it is less suited to be published to be understood as a forecast of likely future conditions. Publishing a forecast that is at odds with otherwise communicated expectations, such as long-run price stability, may confuse observers. Furthermore, in many situations it is very different from the path that policy makers expect for the future and may want to signal to markets. Thus, not surprisingly, most central banks have eventually switched to other conditioning assumptions. Using market expectations of short-term interest rates is rather popular. Galí (2008) notes, however, that it might be difficult to disentangle expected short term interest rates from liquidity and term premia.

An interest rate path that reflects explicitly the views of the monetary policy committee is the most complex choice. While it allows for the most consistent discussion and decision about interest rates, it might create some problems in practice. Perhaps, not all committee members can agree with it. It may be easier for smaller than larger committees to vote on a sequence of interest rates into the future. It may also be difficult to communicate that the path is to be understood by the public as an expectation and not a commitment of policy makers. However, so far central banks practicing this approach such

as those of New Zealand or Norway have reported a positive experience.

The fourth option mentioned above, that is the assumption that central bank interest rates will follow an estimated rule capturing past practice or a rule that is conceived to be optimal, have not been used much in official forecasts. However, this assumption is nevertheless very common in policy analysis presented to central bank decision makers.

Using such a forecast as a basis for discussions among policy makers is appealing for two reasons. First, advantages of rule-based policy have been widely documented in economic research and using rules within forecasts would emphasize the systematic nature of the envisioned policy. Second, a policy rule provides a natural benchmark for discussions how to appropriately adjust the interest rate. The debate in the policy committee could focus on whether the path implied by the rule is appropriate or whether the rule fails to capture certain current developments and thus a deviation is in order.

A rule-based approach would also increase transparency in communicating policy decisions to the public. Policy makers can clearly distinguish between systematic responses to inflation and output and additional responses to other variables that are not included in the rule and comment on reasons for the latter. Already, interest rate prescriptions from different policy rules are routinely computed by the staff of central banks as an input for policy discussions of the decision making committee.

### **Techniques for computing forecasts conditional on an exogenous policy path**

Goodhart (2009) points out that a forecast conditional on an assumed future path for policy is a simulation rather than a forecast and should be interpreted as such. Such a procedure naturally assigns a role to structural macroeconomic models in computing and interpreting forecasts conditional on the exogenous policy path (for applications see for example Smets and Wouters (2004), Adolfson et al. (2007a) and Maih (2010)<sup>34</sup>).

In simulating unchanged-policy scenarios, it is important to incorporate technical restrictions that ensure the existence of unique equilibrium. Macroeconomic models typically exhibit explosiveness or equilibrium indeterminacy when the nominal interest rate does not respond in a stabilization fashion to inflation. Thus, most studies assume that the interest rate is held constant for a certain period and a policy rule kicks in afterwards to ensure the existence of a determinate equilibrium, or the uniqueness of such an equilibrium. Similarly, macroeconomic models that do not exhibit Ricardian equivalence such as the CCTW model require a stabilizing tax policy to ensure convergence to a steady-state debt to GDP ratio.

Given the above restrictions, the temporarily fixed policy period may be simulated by adjusting future policy shocks in a way to keep the policy variable on the assumed path. For example, a constant interest rate path that precedes a return to a policy rule with an endogenous response to inflation, output and the lagged interest rate, could be achieved by choosing policy shocks that exactly offset any reactions to inflation, the output gap and past interest rates over the chosen period.

There are two possibilities to adjust future shocks that have very different implications for the

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<sup>34</sup>The focus in some of these papers is to use conditioning assumptions to include extra information in the model that potentially can improve the forecast.

modeling of market participants' expectations. One approach is to assume that the agents in the model believe that the policy authority follows a rule. Policy shocks designed to keep the policy instrument constant are assumed not to be known to agents in advance. They are surprise shocks and do affect expectations only when they actually occur. Variables that are influenced by expectations about future values of the policy instrument change only gradually since agents do not know these shocks in advance, but only learn about them as they happen. Despite important limitations, this method has been used extensively in central bank circles to simulate constant interest rate scenarios.

First, this method does not provide a good benchmark scenario for policy makers, because it implies that effects of the constant policy assumptions via market expectations are negated. Expectations play a crucial role in macroeconomic policy transmission, and for this reason, feature importantly in DSGE models. These models have been built to analyze effects of policy on endogenous variables through expectations. Thus, it would appear counterproductive to abstract from these effects.

Furthermore, adjusting stochastic policy shocks is only reasonable as long as these adjusted shocks are in the range of historically observed policy shocks. Leeper and Zha (2003) call a policy intervention or shock modest if it "[...] does not significantly shift agents beliefs about policy regime and does not induce the changes in behavior that Lucas (1976) emphasizes." Concerning the constant interest rate scenarios considered at central banks, Smets and Wouters (2004) and Adolfson et al. (2007a) find that the surprise shocks needed in medium-sized DSGE models to keep the interest rate constant cannot be characterized as modest policy interventions, because they are often much larger than historically observed policy shocks.

The second option is to assume that agents in the model incorporate the assumed policy path in their expectation formation regarding future policy. They know the policy shocks that are necessary to keep the interest rate constant in advance. In a sense, the shocks used to adjust policy to the desired path are deterministic and often referred to with this term. Agents' consumption and investment decisions would be based on the anticipation of the exogenous policy path. This procedure accounts for the Lucas critique and all endogenous variables respond in a consistent manner. In forward-looking models, certain exogenous policy scenarios such as a constant interest rate path that lasts for a significant period may have substantial impacts on current values of those variables that are related to market participants expectations of future policy.<sup>35</sup>

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<sup>35</sup>Note, Galí (2008) shows in the context of constant interest rate simulations, that it is also possible to implement unchanged policy without adjusting policy shocks, but by choosing specific policy rules. These policy rules lead to determinacy while at the same time ensuring that the interest rate follows the desired conditional path. However, these policy rules are very different from conventional Taylor type rules. One example is the following rule:  $i_t = i_t^* - \gamma i_{t-1}^* + \gamma(\pi_t + \sigma \Delta y_t)$ , where  $i_t^*$  denotes the desired interest rate path, that includes terms from the IS-curve to fully offset any movements in inflation and the output gap. While using such a rule does not violate the Lucas critique, it does not seem plausible that agents would believe that the central bank pursues a completely different rule than in the past. Therefore, we will focus here on implementations where the central bank keeps following the same policy rule as in the past, but for some period deviates from it by adjusting policy shocks to hold the interest rate constant or on some other exogenous path.

## 5.5 DSGE forecasts conditioned on the 2009 announcement of U.S. fiscal stimulus

To illustrate the conditioning of DSGE model forecasts on a particular policy path we use the CCTW-SW model to evaluate the impact of the U.S. fiscal stimulus in 2009 that was discussed earlier in section 2.1. Specifically, we compute forecasts conditional on an exogenous path for government purchases. The particular path corresponds to the additional purchases announced with the legislation of the American Recovery and Reinvestment Act (ARRA) in February 2009. The values are taken from Table 3 in Cogan et al. (2010). They are given in the first column of said table titled "Increase in Federal Purchases". The additional purchases are highest in 2010 and 2011 but remain modest over all because much of the stimulus was allotted to transfers and tax reductions.

### The fiscal sector of the CCTW-SW model

Before proceeding to a discussion of the simulations, we review the fiscal sector and important related assumptions in the CCTW-SW model. A complete list and description of the equations of the log-linearized version of the model is contained in appendix A.

Government purchases  $G_t$  appear in the resource constraint. Cogan et al. (2010) have added households that do not have access to financial markets and therefore cannot smooth consumption to the model of Smets and Wouters (2007). Such an extension was proposed by Galí et al. (2007) in the context of a small New Keynesian model in order to understand the consequences of fiscal shocks. Only a share  $1 - \omega$  of households indexed by  $j \in [0, 1 - \omega)$  makes optimizing, forward looking decisions and these households have access to financial markets. The remaining share  $\omega$  of households indexed by  $i \in [1 - \omega, 1]$  - the rule-of-thumb consumers - do not have access to financial markets and simply consume their wage income less lump-sum tax payments.

In the absence of rule-of-thumb consumers, the model exhibits Ricardian equivalence, that is, with only permanent-income households that pay lump-sum taxes the timing of taxes and debt is irrelevant. In this case, the only restriction is the intertemporal government budget constraint, i.e. the discounted sum of government budget surpluses must cover the initial debt.

In the presence of rule-of-thumb consumers, the timing of taxes and debt matters. Thus, the CCTW-SW model includes the government budget identity:

$$P_t G_t + B_{t-1} = T_t + \frac{B_t}{R_t}, \quad (22)$$

where  $B_t$  refers to government bonds and  $T_t$  to lump-sum taxes.  $R_t$  denotes the nominal interest rate and  $P_t$  the nominal price level. Since the speed with which government debt is paid off matters for model dynamics, the model is closed with a log-linear fiscal policy rule suggested by Galí et al. (2007). This rule sets the percentage deviation of lump-sum taxes from steady-state,  $t_t$ , in response to deviations of government debt,  $b_t$ , and government purchases,  $g_t$ :

$$t_t = \phi_b b_t + \phi_g g_t, \quad (23)$$

where  $\phi_b$  and  $\phi_g$  determine the elasticities of lump-sum taxes with respect to government debt and government spending.

These taxes are "lump sum" in the sense that they do not affect incentives to work, save or invest. They do, however, lower future after tax earnings and thereby wealth. Because of the absence of taxes that distort incentives, the model is not suited for analyzing the longer-term consequences of fiscal policy. However, it may well be used to analyze temporary changes in government purchases as in Cogan et al. (2010)'s analysis of the ARRA.<sup>36</sup>

### **ARRA simulations by conditioning on policy shocks**

We consider both methods for conditioning on a policy path by adding suitably chosen shocks that are discussed in the preceding section. Of course, given that the ARRA legislation was announced and known to the public, the use of deterministic shocks that treat the additional government purchases as anticipated is much more appropriate than the stochastic shocks which treat the additional purchases as surprises. Nevertheless, we simulate the stochastic case for comparison because it has been widely used at central banks in the context of interest rate policy. Our example will serve to illustrate that it is rarely appropriate.

The stochastic shock case is implemented in the DYNARE model solution software (see Juillard, 2001) and thus easily usable. The software computes the policy shocks that are necessary to keep government purchases on the proposed future path.

**Figure 10** reports the forecasts obtained with the CCTW model from section 5.3. The data goes through 2009Q1 and the forecasts start in 2009Q2, that is right after the ARRA legislation was passed. Coincidentally, the recession started to fade and the recovery gained ground in subsequent quarters.

The solid black line refers to the data and the solid gray line to the forecast without information on ARRA purchases. The dashed line indicates the forecast conditioned on ARRA purchases simulated with stochastic shocks. The dashed-dotted line reports the forecast conditioned on ARRA purchases simulated with anticipated shocks.

Generally, the inclusion of ARRA purchases does not change the forecast very much. The top right panel indicates that the level of GDP is a bit higher throughout the forecast if ARRA purchases are included explicitly. Thus, it has a stimulative effect. However, both, consumption and investment growth are lower than in the forecast without ARRA. Increased government spending crowds out private spending. The stimulative effect is a bit larger in the simulation with stochastic shocks than in the simulation with anticipated deterministic shocks. The reason is that households reduce consumption initially more if they anticipate higher government spending to persist in the future. Given that the ARRA was public information, the simulation with stochastic shocks overstates the likely GDP impact of the fiscal stimulus.

For a thorough analysis of these methods in the context of simulating exogenous central bank

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<sup>36</sup>Drautzburg and Uhlig (2011) show that if one takes incentive effects through increases in distortionary taxes into account in evaluating the impact of ARRA spending an increase in government spending would eventually reduce real GDP. They show that such a decrease of real GDP through increases in distortionary taxes can be long lasting. Cogan et al. (2012) go beyond an analysis of temporary changes in government purchases and taxes and analyse permanent changes in government purchases, transfers and distortionary taxes in the context of fiscal consolidation proposals for the US economy.

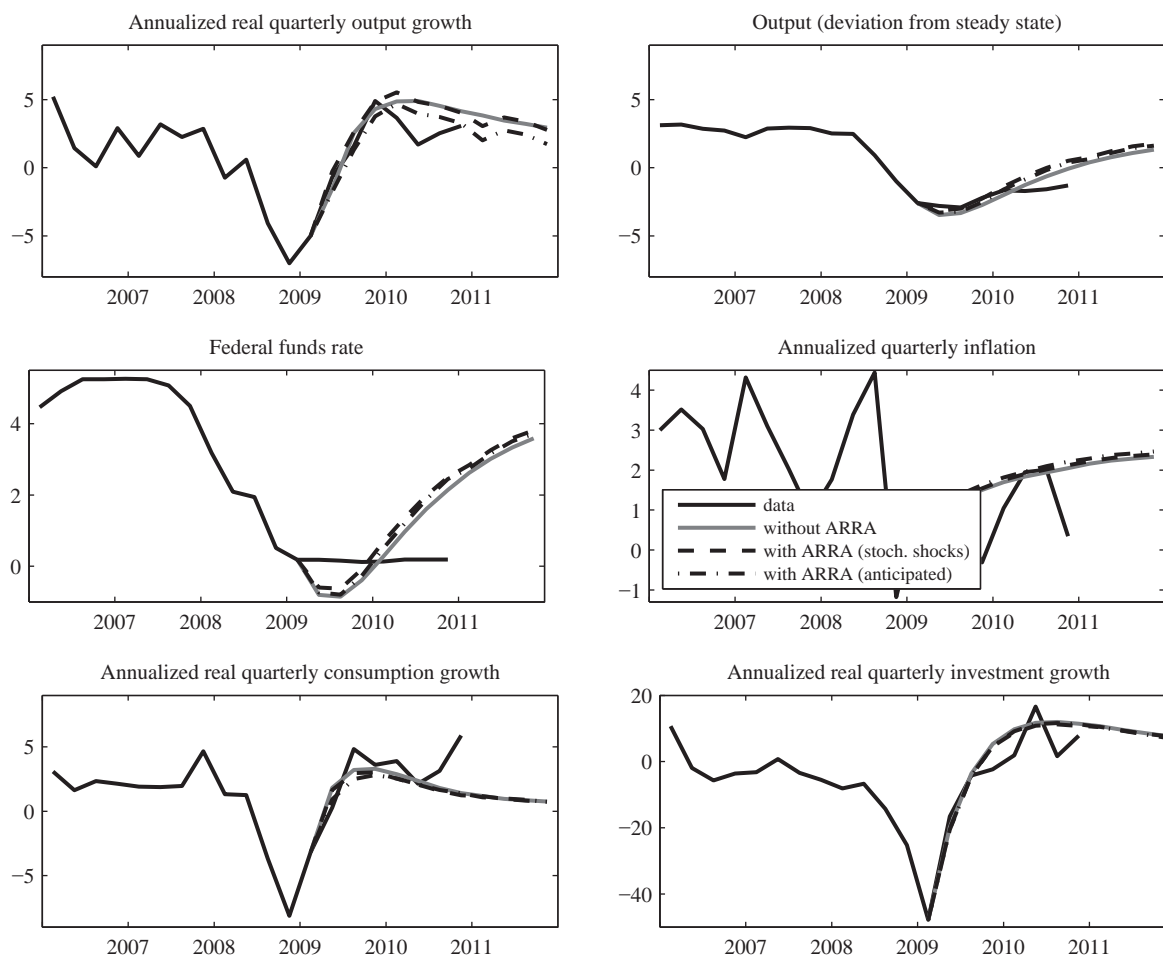


Figure 10: Conditioning 2009:Q2 forecasts on announced ARRA government purchases: Data (solid black line), forecast without ARRA (solid gray line), forecast with ARRA stochastic shocks (dashed line), forecast with ARRA anticipated (dashed-dotted line)

interest rate paths the reader is referred to Galí (2008). He shows that different implementation strategies of an interest rate path lead to different projected output and inflation dynamics. This is due to a multiplicity of possible combinations of the real interest rate and expected inflation that lead to the same nominal interest rate. Thus, it is crucial to consider which is more appropriate in the particular situation the forecast is made and used in policy deliberations. Also, in terms of publishing forecasts it is important to explain the procedure used. "A complete description would need to include the nature and specification of the policy rule that will be followed in order to support the desired interest rate path." (Galí, 2008, p. 16). This might be difficult in practice and is an additional argument for basing central bank forecasts on a specific announced policy rule, rather than on a hypothetical interest rate path.

We close this section with a discussion of the interaction of monetary and fiscal policies at the zero lower bound on nominal interest rates. In the debate on the desirability of fiscal stimulus packages it has repeatedly been emphasized that fiscal stimulus has greater multiplier effects in the event when nominal interest rates are constrained at the zero interest rate floor. In this situation, fiscal stimulus

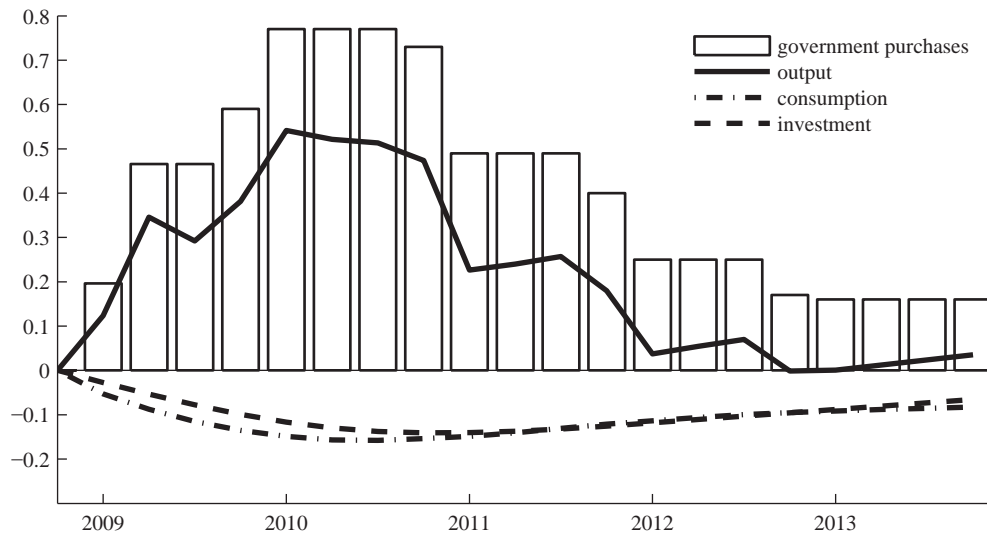


Figure 11: GDP, consumption and investment forecasts: Anticipated government purchases and explicit zero bound on nominal interest rates.

does not induce an immediate increase in interest rates because the notional interest rate target of the central bank is in negative territory.

Indeed, the first panel in the second row of **Figure 10** shows negative nominal interest rates in 2009. To investigate the impact of the zero lower bound on nominal interest rates we introduce this non-negativity constraint explicitly in the model structure.<sup>37</sup> Such a formulation is necessary to be able to determine the number of quarters for which the nominal interest would stay at the zero bound endogenously. As a consequence of the non-negativity constraint, the model needs to be solved by means of nonlinear methods. We make use of the stacked-Fair-Taylor algorithm implemented in DYNARE (see Juillard, 1996).

**Figure 11** reports the GDP impact (solid line) of the ARRA government purchases when the zero bound is implemented explicitly. The information shown in the figure is the difference between the simulations with and without ARRA purchases using anticipated shocks. The model forecast implies that the nominal interest rate (not shown) stays at zero for three quarters. The bars indicate quarterly ARRA purchases as a share of GDP. The GDP impact is lower than the government purchases throughout the simulation. In other words, the multiplier is below one. Private consumption and investment are reduced relative to the simulation without fiscal stimulus. The GDP impact of fiscal stimulus is only slightly greater than in the simulation without the zero bound.

Note, the data shown in **Figure 10** indicates that the nominal interest rate stayed at zero longer than implied by the forecast with the explicit zero bound. However, this finding is consistent with output staying below the level predicted by the same forecasts, and thus monetary policy continuing to remain accommodative.

<sup>37</sup>See Orphanides, Coenen and Wieland (2004) for the functional form.



## 5.6 Forecast comparison and forecast accuracy

Whether forecasts are useful for policy design depends on their accuracy. Thus, we compare the quality of inflation and output growth forecasts from the Fed's Greenbook and from the Survey of Professional Forecasters (SPF) with forecasts from the different types of macroeconomic models considered in the previous sections.

The SPF is a quarterly survey of professional macroeconomic forecasters conducted by the Federal Reserve Bank of Philadelphia. Typically, 30 to 50 respondents report projections of several key macroeconomic variables. The mean of the SPF forecasts is often more accurate than individual forecasts and can serve as an important source of information for policy makers regarding private sector expectations.

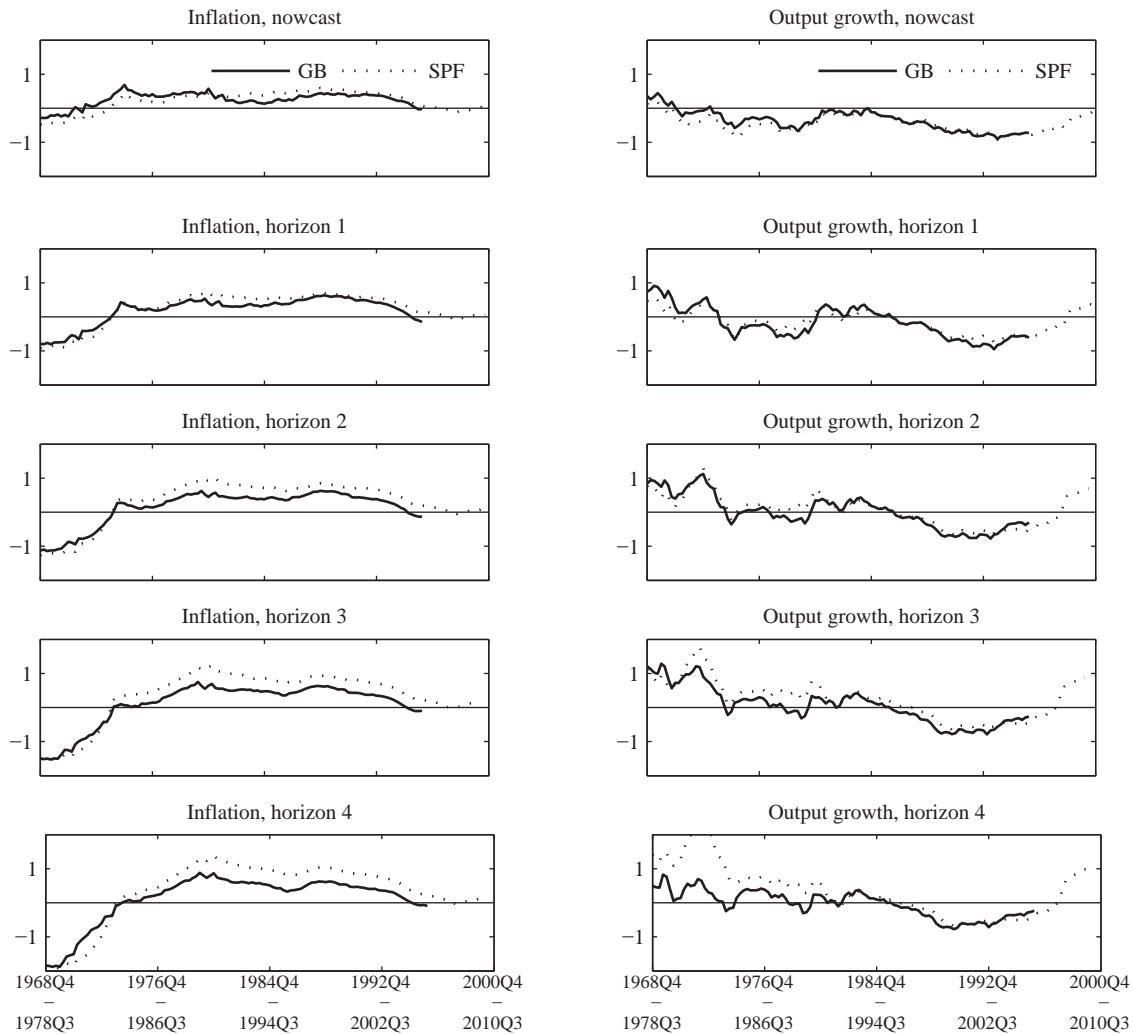
We first check whether forecasts are unbiased, then we will check how model-based forecasts compare in terms of accuracy to forecasts from professional forecasters and policy institutions. With regard to the latter, we focus on predictions around turning points because downturns and recoveries pose the greatest challenge for economic forecasters.

### Forecast bias

A good forecast should not be systematically higher or lower than the actual values of the forecasted variable if the forecast is based on a symmetric loss function. Otherwise there would be systematic forecast errors and the forecast would be biased. An exception is the case of an asymmetric loss function as we discussed in section 2. but even if forecasts for fiscal or monetary policy purposes are based on asymmetric loss functions, it is still of interest to check whether forecasts are biased and to assess whether such a bias can be rationalized by assuming a specific asymmetric loss function.

**Figure 12** plots a measure of the forecast bias for the Greenbook forecasts (solid line) and the mean forecast of the Survey of Professional forecasters (SPF, dotted line) and indicates how the bias varies over time.

The sample of Greenbook forecasts ends in 2005 as Greenbook data remains confidential for five years. We measure the forecast bias as the average of the forecast error:  $1/T \sum_{t=1}^T E_t(y_{t+h}) - y_{t+h}$ , where  $T$  denotes the number of forecasts that is taken into account,  $E_t(y_{t+h})$  refers to the forecast for horizon  $h$  and  $y_{t+h}$  denotes the data realizations. We focus on quarterly annualized output growth and quarterly annualized inflation forecasts. The definition of data realizations is not a trivial choice as output growth data is revised substantially over time. GDP data is first released about one month after the end of the quarter to which the data refers, the so-called advance release. These data are then revised several times at the occasion of the preliminary release, final release, annual revisions and benchmark revisions. We follow Faust and Wright (2009) and use the data point in the vintage that was released two quarters after the quarter to which the data refer to as revised data. For example, revised data for 2001:Q1 is obtained by selecting the entry for 2001:Q1 from the data vintage released in 2001:Q3. To study how the bias has changed over time we plot the average forecast error over a moving window of 40 quarterly observations, i.e. of 10 years.



**Figure 12:** The graphs shows time variations in forecast bias. Bias is measured as the average forecast error of Greenbook (GB) and SPF forecasts over a moving window of 40 observations each. We use the data point in the vintage that was released two quarters after the quarter to which the data refer to as revised data. Inflation is defined as annualized quarterly inflation and output growth is defined as annualized quarterly output growth.

The panels in **Figure 12** show that Greenbook and SPF inflation forecasts exhibited an upward bias from about 1975 to 2000. Forecasters overestimated inflation by up to 1 percent. The bias is somewhat smaller for the Greenbook than for the SPF. The bias increases with the forecast horizon. The bias decreased in the 1990s and has disappeared for recent observations. Inflation bias would be consistent with asymmetric loss. The time-varying nature of this bias, however, may be more difficult to rationalize. Moreover the bias is similar for the Greenbook and the SPF forecasts. While the former is a forecast from a policy institution which might weigh positive and negative forecast errors differently, it is more difficult to see why private sector forecasters would also weigh them asymmetrically. Another reason for this bias could be the great moderation. Inflation rates have decreased since the early 1980s. If forecasters use econometric models estimated on past data, it is likely that they included the high trend inflation from past data and thus overestimated future inflation.

Output growth forecasts are negatively biased for the 1990s. Output growth was very high especially in the late 1990s due to high productivity growth. This result is consistent with Patton and Timmermann (2007). They find that Greenbook forecasts are suboptimal under a symmetric loss function. However, the forecasts are optimal if overpredicting output growth is more costly than underpredicting. They find that this asymmetry also depends on the level of output growth and is more important during periods of low growth. In such periods they find that overpredictions of GDP growth are more than three times as costly to the Fed as underpredictions, whereas in times of high growth overpredictions are only about 25% more costly than underpredictions. A reason for such a loss function might be that overpredicting output growth after a recession might incorrectly signal a strong recovery and could result in an overly tight monetary policy increasing the danger of falling back into a recession.

An alternative explanation is that a long period of unusually high output growth led to an underprediction of growth rates with econometric models based on past data. At the end of the sample the bias is positive, especially for high forecast horizons, which might be influenced by data from the recent financial crisis. As we will show in more detail below, professional forecasters were not able to predict the deep recession of 2008/2009 and thus over-predicted growth rates.

A good forecast should not exhibit systematic errors unless the forecast is based on an asymmetric loss function. Theil notes: *“If there are any errors in the forecasting process on which the measures taken are based, the measures themselves will in general be suboptimal. Hence a preliminary analysis of forecasts and especially of forecasting errors must be considered useful. Of course, forecasting in the field of economics is a hazardous enterprise, so that errors as such need not amaze us; but if it were possible to detect forecasting errors which we might call “systematic,” this could be helpful to find systematic failures in the adaptation of instruments, and it might be possible to indicate ways in which such failures can be avoided, at least approximately”* (Theil, 1958, p. 3).

To test whether the bias we found is significant and whether the forecasts are optimal in the sense that forecast errors are unpredictable, we use Mincer-Zarnowitz regressions (Mincer and Zarnowitz, 1969). We regress data realizations on a constant and the forecasts:

$$y_{t+h} = \alpha + \beta E_t(y_{t+h}). \quad (24)$$

If the forecast error is unpredictable and thus the forecast unbiased, then  $\alpha = 0$  and  $\beta = 1$ . If the intercept is different from zero, then the forecast has been systematically higher or lower than the actual data. If the slope is different from one then the forecast has systematically over- or under-predicted deviations from the mean (see e.g. Edge and Gürkaynak, 2010).

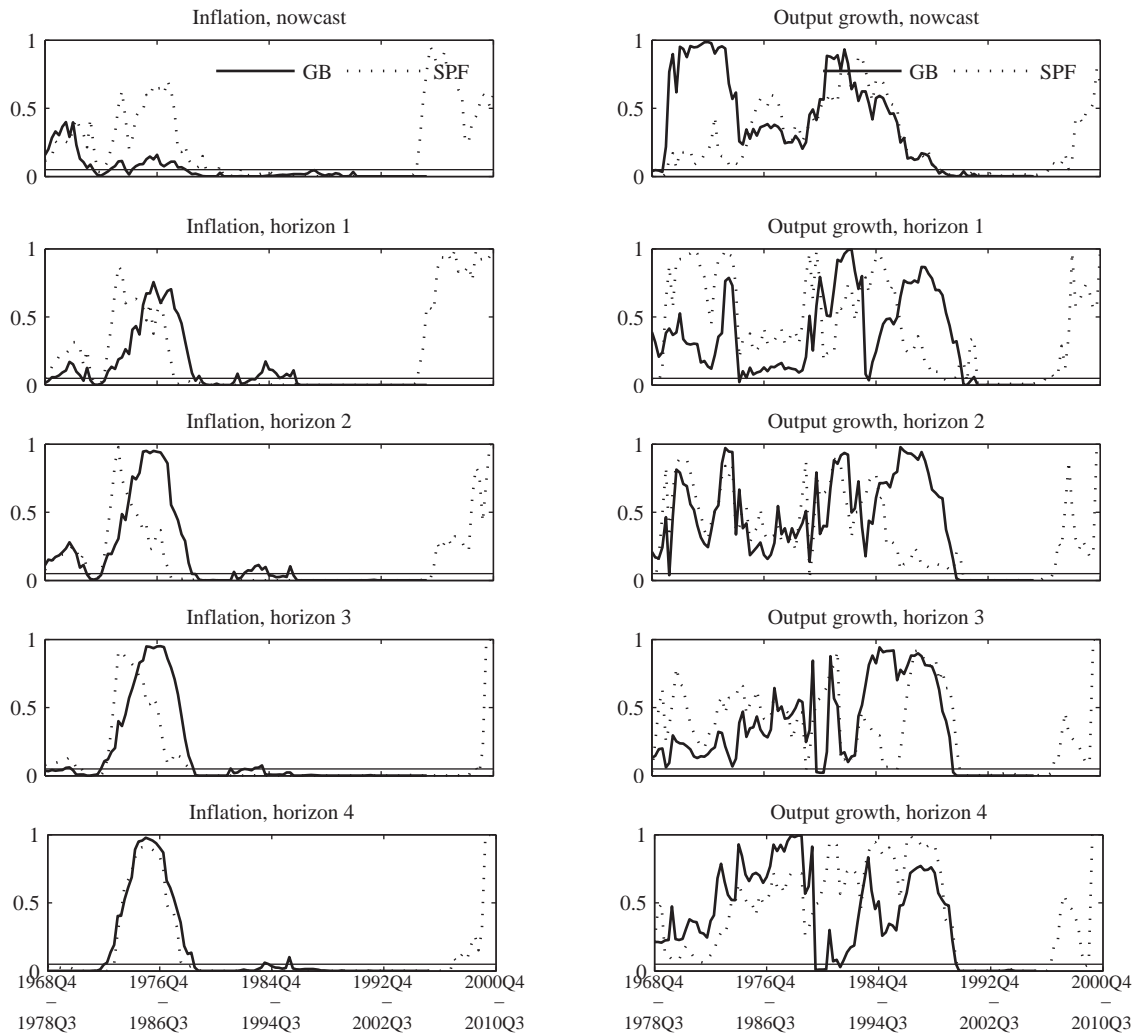
We run the Mincer-Zarnowitz regression and estimate Newey-West standard errors with the number of lags equal to the forecast horizon to take into account serial correlation of overlapping forecasts. We conduct F-tests of the joint null hypothesis  $\alpha = 0$  and  $\beta = 1$ . We run these tests for the moving window of 40 quarterly forecasts to check whether forecasting accuracy has changed over time.

**Figure 13** plots the p-values of the test for forecast optimality for the Greenbook (solid line) and SPF (dotted line) forecasts. A p-value smaller than 0.05 indicates a rejection of the null hypothesis of optimal forecasts on the 5% level, which implies a significant bias. The p-values reflect the magnitude

of the estimated bias shown previously. Greenbook and SPF inflation forecasts are significantly biased from about 1980 to 2000, the time with the highest estimated inflation bias. The length of the bias period increases with the forecast horizon. More recently, the bias has disappeared from the SPF forecasts. Unfortunately, the Greenbook forecasts are not yet available for recent years to check whether they have also turned unbiased. Output growth forecasts are unbiased for large parts of the sample. Only the systematic under-prediction of output growth in the 1990s is statistically significant.

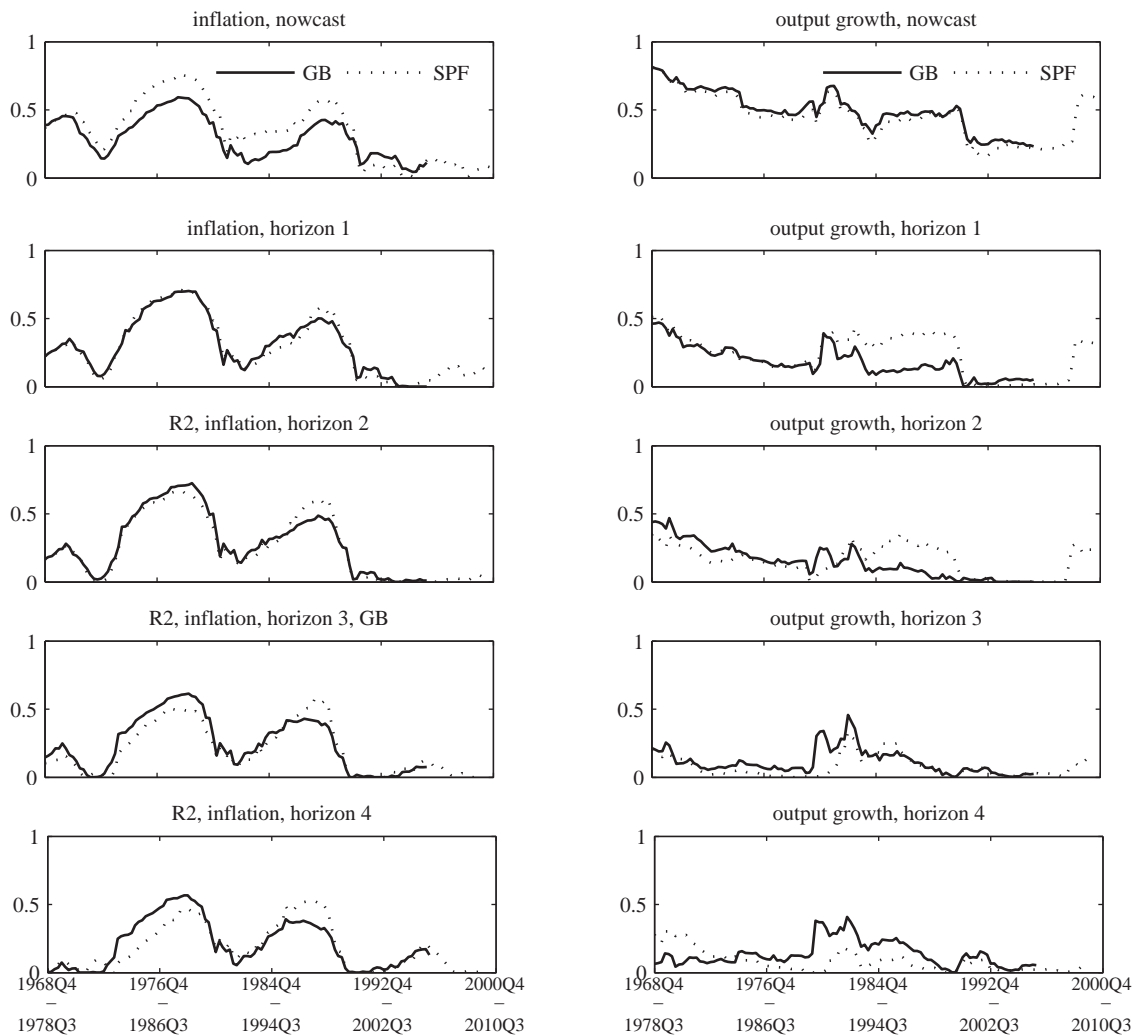
### Information content of forecasts

While the previous statistics show whether a forecast can be improved by eliminating a systematic bias, they do not indicate whether forecasts contain much information about actual future



**Figure 13:** The graphs shows time variations in the efficiency of Greenbook (GB) and SPF forecasts measured by the p-value of a F-test of the joint null-hypothesis of optimal forecasts  $\alpha = 0$  and  $\beta = 1$  in the Mincer-Zarnowitz regression  $y_{t+h} = \alpha + \beta E_t y_{t+h}$ . A p-value smaller than 0.05 rejects the null hypothesis of optimal forecasts on the 5% level. A p-value larger than 0.05 shows that we cannot reject the null hypothesis of optimal forecasts. The straight horizontal line indicates a p-value of 0.05.

economic developments, and therefore constitute valuable information for policy makers. One way to assess the information content of forecasts is to check how much of the variability of the data is explained by the forecasts. We use the  $R^2$  from the Mincer-Zarnowitz regressions to evaluate the informational content of forecasts. The  $R^2$  can be directly interpreted as the fraction of the variance in the data that is explained by the forecasts. This fraction will be always below 1 as there are shocks and idiosyncrasies that no economic model can capture. **Figure 14** shows the  $R^2$  from the rolling window regressions.



**Figure 14:** The graphs shows the  $R^2$  in the Mincer-Zarnowitz regression  $y_{t+h} = \alpha + \beta E_t y_{t+h}$  for Greenbook (GB) and SPF forecasts. A high value shows that a large fraction of the variance in the data is captured by the forecasts. A low value shows that forecasts can explain little of the variation of the forecasted variable.

The results are similar for the Greenbook and SPF forecasts. They show that the  $R^2$  decreases with the forecast horizon. This finding indicates that it is more difficult to predict developments further ahead. Interestingly, the  $R^2$  for the nowcasts is substantially below unity over the whole sample. The  $R^2$  varies a lot over time taking values roughly between 0.1 and 0.6 for inflation. However, for the

last 20 years the informational content of the inflation forecasts has dropped to values close to zero. A reason may be that the volatility of inflation has fallen to rather low level since the early 1990s. Inflation can now be characterized as idiosyncratic deviations from a low constant rate. Stock and Watson (2007) show that the predictable, that is permanent component of inflation has been fairly high in the 1980s but has almost disappeared in the 1990s. The remaining fluctuations of inflation are not persistent and thus hardly predictable. Monetary policy may have been a key factor causing inflation to be difficult to forecast. Given a sufficiently high inflation response monetary policy might eliminate any lasting deviations from trend inflation or the inflation target (see e.g. Benati, 2008; Gerlach and Tillmann, 2010, for some empirical evidence from inflation targeting central banks).

With regard to output growth, nowcasts explain a larger fraction of the variability of data realizations than in the case of inflation. However, the predictability of output growth quickly decreases with the forecast horizon and is close to zero for forecast horizons 2-4. Even the nowcast can only explain on average 50% of the variance of output growth data. This is not too surprising given the fact that output growth estimates are heavily revised even after the first data releases.<sup>38</sup> There is one period in the sample for which the informational content of output growth forecasts is especially low: the 1990s. For this period we also found a large forecast bias. Given the difficulties in forecasting output accurately beyond the nowcast, it is not surprising that policy institutions, and central banks in particular, put a lot of effort in estimating at least the current state of the economy relatively precisely.

### **Predicting turning points**

In the following, we focus more closely on turning points in the business cycle. Forecasting performance during those periods is particularly important to policy makers. In doing so we will also compare the performance of model-based forecasts to Greenbook and SPF forecasts.

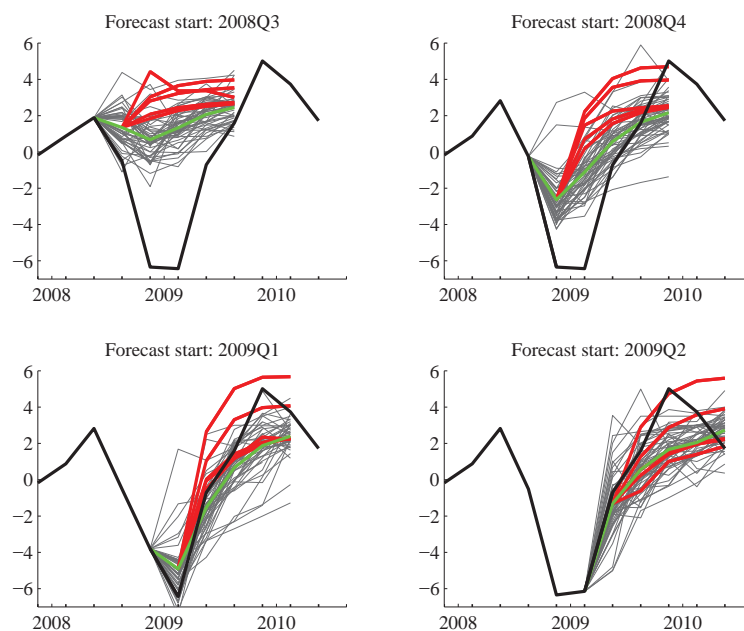
Wieland and Wolters (2011) investigate the accuracy of forecasts from the SPF, the Greenbook and six macroeconomic models during the five most recent U.S. recessions. The six macroeconomic models considered in their paper are three small-scale New-Keynesian models, a Bayesian VAR model and two medium-scale DSGE models. The models are estimated on real-time data vintages that were also available to professional forecasters at the time when forecasts were computed.<sup>39</sup>

**Figure 15** shows output growth forecasts from the SPF, the Greenbook, and the six macroeconomic models for the 2008/2009 U.S. recessions. The black line shows real-time data until the forecast starting point and revised data afterwards. The grey lines correspond to individual forecasts from the SPF. The green line indicates the mean SPF forecast. The red lines are the model-based forecasts. Professional forecasters, on average failed to foresee the recession caused by the financial crisis, even

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<sup>38</sup>It would be interesting to compute the  $R^2$  of the advance release of GDP in a Mincer-Zarnowitz regression. Even this first official estimate of GDP probably explains much less than 100% in the variability of revised GDP data.

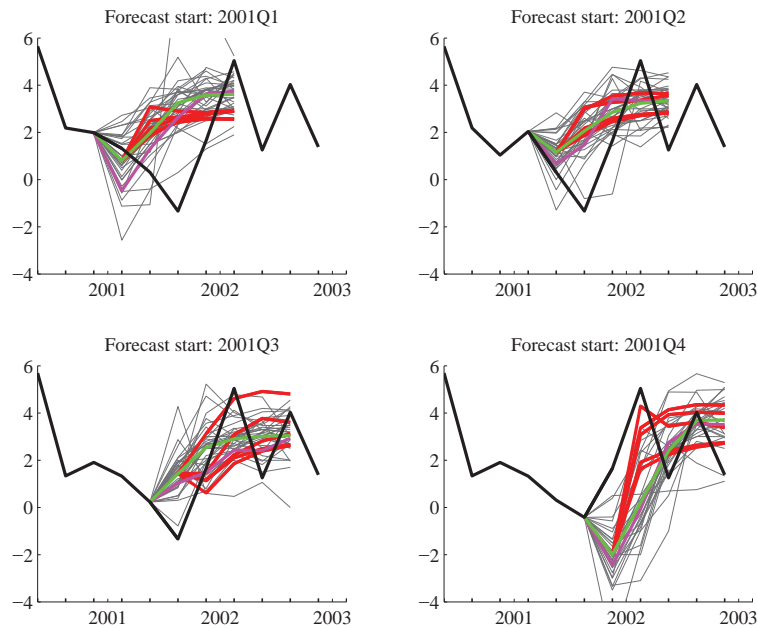
<sup>39</sup>The macroeconomic models are estimated on quarterly data and thus have a disadvantage for computing a nowcast as they cannot use within quarter information from higher frequency data. We eliminate this informational advantage by conditioning the model forecasts on the Greenbook nowcasts and for the most recent recession on the mean SPF nowcast.



**Figure 15:** The graph shows output growth forecasts from the SPF, the Greenbook, and six macroeconomic models for the most recent U.S. recessions. The black line shows real-time data until the forecast starting point and revised data afterwards. The grey lines show individual forecasts from the SPF. The green line shows the mean of the SPF forecasts. The red lines show the model-based forecasts.

as late as in the third quarter of 2008. The mean SPF forecast indicates a slowdown in the fourth quarter followed by a return to higher growth in the first quarter of 2009. The model-based forecasts would not have performed any better. In fact, they do not indicate any impending decline in economic activity. In the fourth quarter of 2008, following the Lehman debacle, professional forecasters drastically revised their assessments downwards, and continued to do so in the first quarter of 2009. From 2009Q2 onwards, the model-based forecasts perform quite well in predicting the recovery of the U.S. economy. From that point onwards, several of the models deliver predictions that are very similar to the mean SPF forecast and match up with the subsequent data releases well. Studying all the individual forecasts from the SPF, it is clear that not a single forecaster delivered a point forecast of the deep recession.

**Figure 16** shows a similar figure for the 2001 recession. It confirms that model-based as well as SPF-forecasts have difficulties predicting accurately beyond the nowcast. For this recession Greenbook projections are also available. The Greenbook projections (purple line) do not predict the recession any more accurately. In 2001Q1 and 2001Q2 the nowcast of most forecasters shows a decline in growth which is relatively accurate. However, most forecasters predicted an increase in growth from horizon 1 onwards. Revised data shows that growth moved in the opposite direction towards negative growth rates. In 2001Q3 model-based forecasts, SPF forecasts and Greenbook projections predicted a recovery. The actual recovery started one quarter later. In 2001Q4 the recovery took place, but all forecasters missed it and predicted a much lower nowcast. This example reinforces that it is very difficult to predict recessions and business cycle turning points.



**Figure 16:** The graph shows output growth forecasts from the SPF, the Greenbook, and six macroeconomic models for the most recent U.S. recessions. The black line shows real-time data until the forecast starting point and revised data afterwards. The grey lines show individual forecasts from the SPF. The green line shows the mean of the SPF forecasts. The purple line shows the Greenbook projection and the red lines show the model-based forecasts.

Forecasts during the recession in the early 1990s (not shown) indicate that forecasters also failed to predict this recession. However, once the downturn took place in 1990Q4 SPF forecasters and Greenbook projections predict the recovery relatively well. The model-based forecasts show an upward bias similar to what we observed for the 2008Q4 predictions. The recovery in 1991Q1 and 1991Q2 is predicted relatively precisely by the SPF forecasters and some of the model forecasts. Two of the models as well as the Federal Reserve predicted higher growth rates.

While model forecasts exhibited an upward bias compared to the professional forecasts for the 2008/2009 and the early 1990s recession, the mean SPF forecast is within the range of the model-based forecasts for the 2001 recession. Thus, stylized macroeconomic models perform not much worse than professional forecasters even though the number of data series used by models is only a small fraction of the data universe that experts can look at and judge to be important. Thus, once models are add-factored with such judgements they may do just as well or possibly even better than the expert forecasts. Similar graphs can be produced for inflation forecasts (not shown here). They tend to confirm that model-based forecasts are roughly in line with expert forecasts.

### **Comparing the accuracy of model-based and expert forecasts**

The results above show that economic forecasting is an extremely difficult endeavor. There are clearly limitations to the accuracy of forecasts especially around turning points that policy makers should be aware of. The policy process often relies on forecasts that are conditional on exogenous policy assumptions. As discussed in section 5.4 structural models are well suited for such exercises.



Table 9: RMSEs of Forecasts Initialized with Expert Nowcasts

Sample / Horizon	Inflation			Output Growth		
	Mean	GB	SPF	Mean	GB	SPF
1980:1 - 1981:3						
0	1.67	1.67	1.52	5.05	5.05	—
1	2.59	1.25	1.81	5.83	6.65	—
2	2.59	1.66	1.92	4.83	5.54	—
3	1.73	1.77	2.23	5.20	6.11	—
4	3.22	2.21	2.56	4.05	5.32	—
1981:4 - 1983:4						
0	1.12	1.12	1.13	2.42	2.42	2.14
1	1.86	1.32	1.76	3.54	3.58	3.88
2	1.92	1.26	1.68	3.86	3.93	4.11
3	1.79	1.07	1.95	4.25	3.91	4.41
4	1.87	1.48	2.06	4.28	3.84	4.02
1990:1 - 1992:1						
0	0.73	0.73	1.09	1.27	1.27	1.12
1	1.03	0.84	0.98	2.47	2.09	1.45
2	1.23	0.95	1.01	2.82	2.34	2.06
3	1.20	1.06	1.19	2.94	2.31	2.54
4	1.16	1.02	1.19	2.69	2.18	2.37
2000:4 - 2002:4						
0	0.56	0.56	0.70	2.28	2.28	2.22
1	0.85	0.87	0.87	2.23	2.20	2.30
2	1.23	0.70	0.92	2.11	2.34	2.21
3	1.25	0.75	0.93	2.65	2.76	2.65
4	1.45	0.78	0.98	2.19	2.18	2.13
2007:4 - 2009:3						
0	1.11	—	1.11	1.94	—	1.94
1	1.10	—	1.03	4.21	—	3.30
2	1.28	—	1.10	4.89	—	4.11
3	1.51	—	1.24	5.32	—	4.80
4	1.65	—	1.40	5.70	—	5.39

Given the limitations of forecasting the performance of structural models relative to expert forecasts such as the SPF and the Greenbook is of interest. Thus, we now investigate the relative performance more systematically. To this end, we compute the root mean squared prediction errors (RMSE) for all forecasts.

**Table 9** reports the RMSE of the mean forecast of the six models, the Greenbook and the mean forecast of the SPF for inflation and output growth for the five most recent NBER defined US recessions. The typical sample covers the period from 4 quarters prior to the trough determined by the NBER to 4 quarters after the trough.

In most cases model forecasts for inflation are on average somewhat less accurate than the Greenbook and mean SPF forecasts. The Greenbook forecasts are in turn more accurate than the mean SPF forecast. Regarding output growth forecasts from models and professional forecasters are very similar. Only for the 2008/2009 recession the SPF forecasts are more accurate than the model forecasts. For all other recessions there is not much of a difference between model forecasts, Greenbook projections

and SPF forecasts. Wieland and Wolters (2011) report that individual models perform worse than their mean forecast. This is also true for the SPF (see e.g. Timmermann, 2006, on forecast averaging). Using a variety of different forecasting tools as currently practiced by many policy institutions is thus important to increase the accuracy of a final overall forecast.

## **6 Evaluating the performance of policy rules that respond to forecasts**

Given the lack of accuracy of available model and expert forecasts and the heterogeneity resulting from reasonable differences in modeling assumptions, it is important to investigate whether policy maker decisions should explicitly and directly respond to changes in forecasts rather than recent data realizations. This question is of importance for many areas of policy making including monetary and fiscal policy. Answering this question requires simulating feedback rules in structural models that account for the interaction of economic forecasts with policy decisions. The type of models presented in the preceding section can be used for analyzing forecast-based feedback rules for monetary and fiscal policy instruments. Of course, space limitations in this chapter require us to select a particular example rather than covering a wide range of different policy instruments. Since we have provided new empirical evidence regarding direct responses of policy decisions to policy maker forecasts in the case of the U.S. Federal Open Market Committee (FOMC) in section 4, we now also evaluate the performance of such rules for the federal funds rate in models of the U.S. economy.

Several authors (see e.g. de Brouwer and Ellis, 1998; Laxton et al., 1993; Black et al., 1997) have analyzed the performance of forecast-based monetary policy rules in specific models. Using multiple models in parallel makes it possible to investigate the importance of different structural modeling assumptions for policy design.

To this end, we simulate rules with different horizons for inflation and output forecasts in three models: the small IMF quarterly projection model of the U.S. by Carabenciov et al. (2008); the medium-size DSGE model by Cogan et al. (2010) (CCTW-SW), and the linearized version of the FRB/US model used by Levin et al. (2003); (see also Brayton and Tinsley, 1996; Reifschneider et al., 1999). The version of the IMF-model we use is the one estimated in section 5.2 with U.S. data from 1994Q1 to 2007Q4. The version of the CCTW-SW model is the one estimated in section 5.2 with data from 1965Q3 to 2007Q4. For the FRB/US model we use the same parameter values as in Levin et al. (2003). These parameters have been estimated at the Federal Reserve.

We compare the performance of policy rules across models and search for optimized rules given a loss-function of the policy maker. In this manner, we investigate whether the conventional wisdom that monetary policy should be forward-looking because of the existence of transmission lags is borne out by modern macroeconomic models. The exercise is similar in spirit to Levin et al. (2003) who optimize simple forecast-based policy rules for five different models of the U.S. economy.

## 6.1 Optimizing forecast-based rules for central bank interest rates

We start by determining the optimal response coefficients and horizons concerning inflation and output gap forecasts in the following type of interest rate rule:

$$i_t = \rho i_{t-1} + (1 - \rho)[i^* + \beta(E_t \pi_{t+h_\pi} - \pi^*) + \gamma E_t y_{t+h_y}], \quad (25)$$

Here  $i_t$  denotes the nominal interest rate,  $\pi_t$  the average annual inflation rate,  $y_t$  the output gap,  $\pi^*$  the inflation target and  $i^*$  the desired nominal interest rate when inflation and output equal their respective targets. The nominal interest rate is measured at annual rates in percentage points. The parameters  $h_\pi$  and  $h_y$  denote forecast horizons measured in quarters.

### Forecast horizons and equilibrium determinacy

In searching for policies that deliver good stabilization performance we will focus on rules that yield determinacy, i.e. a unique stationary rational expectations equilibrium. Rules that lead to indeterminacy are not desirable because they may induce fluctuations unrelated to economic fundamentals. The models are too complex to identify determinacy conditions analytically. Thus, we use numerical methods to check whether the models exhibit determinacy for specific policy parameter combinations. **Figure 17** shows determinacy regions for different combinations of the interest rate smoothing and inflation response coefficients under a range of forecast horizons. The output gap coefficient is restricted to zero, ( $\gamma = 0$ ). The shaded areas depict the determinacy regions.

In the absence of interest-rate smoothing, ( $\rho = 0$ ), the interest rate response to inflation must simply be greater than one to ensure equilibrium determinacy. This condition, which implies that central banks act sufficiently to increase the real interest rate in response to an increase in inflation, is well-known and often referred to as the Taylor principle. For interest rate rules that respond to recent outcomes of inflation ( $h_\pi = 0$ ) the determinacy regions are very large. The determinacy regions shrink with rising forecast horizons ( $h_\pi > 0$ ). Only the IMF-model is relatively immune to indeterminacy problems due to its high degree of intrinsic inflation persistence. Some studies have suggested that interest rate smoothing coefficients larger than one can yield a unique determinate equilibrium. This is not the case in the models analyzed here. An interest rate coefficient equal to or larger than one leads to explosive dynamics in all three models unless the inflation response is lower than one.

**Figure 18** plots determinacy regions for rules with a unit reaction to the current output gap ( $\gamma = 1$ ,  $h_y = 0$ ). Allowing for an additional response to the current output gap increases the determinacy regions especially for moderate horizons of the inflation forecast of up to four quarters. The output gap is an indicator of future inflation and can increase the link between current and expected future inflation. This finding holds also for an increase in the interest rate smoothing coefficient. Both lead to a more stabilizing policy and thus larger determinacy regions.

So far, our analysis has uncovered several conditions that render policy rules stabilizing: responding to current inflation or a near-term inflation forecast, an additional response to the output gap, and a substantial degree of interest rate smoothing.

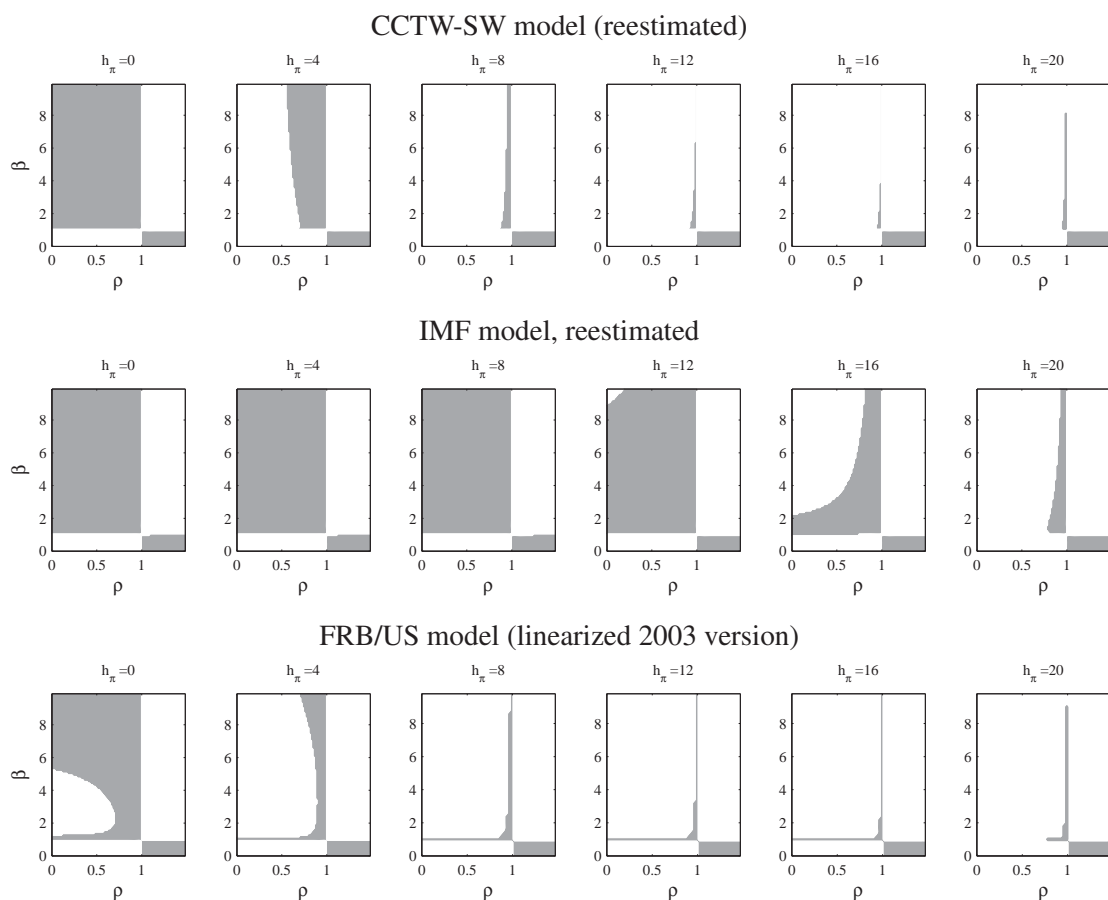


Figure 17: The graphs show determinacy regions for different combinations of the inflation response coefficient  $\beta$  and the interest rate smoothing coefficient  $\rho$ . The response to the output gap is zero ( $\gamma = 0$ ). For each specification of the inflation forecast horizon (0, 4, 8, 12, 16 and 20 quarters), multiple equilibria occur for all combinations of the parameters  $\alpha$  and  $\rho$  that lie outside of the shaded area.

### Optimizing forecast-based rules

Having analyzed general conditions that lead to a unique stable equilibrium we now investigate rules with response coefficients optimized to a particular model. In optimizing coefficients we have in mind a policy maker who cares about stabilizing inflation and the output gap. Thus, we consider policymaker preferences that can be represented by a simple loss function of the following form:

$$L = var(\pi) + \lambda var(y), \quad (26)$$

where  $var(\cdot)$  denotes the unconditional variance and the weight  $\lambda \geq 0$  indicates the policymaker's preference for reducing output variability relative to inflation variability. The loss function is a one-period version of the loss function in equation (1).

One might ask why not use a welfare function that is based on household utility (see e.g. Schmitt-Grohé and Uribe, 2007). We use a traditional ad hoc loss function (this approach goes back to the work by Tinbergen, 1952; Theil, 1958), because only one of the three models considered here (CCTW-SW) would allow the derivation of a loss function from household utility. While the equations in the

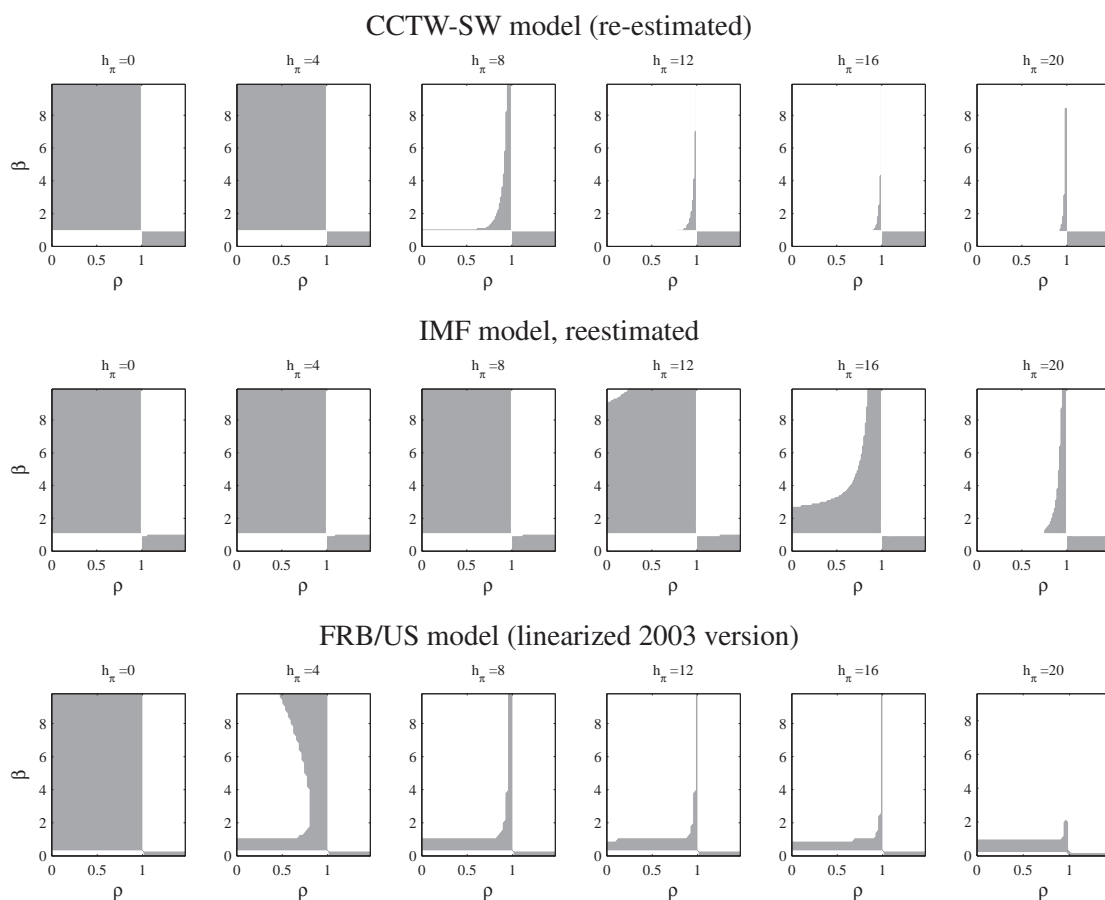


Figure 18: The graphs show determinacy regions for different combinations of the inflation response coefficient  $\beta$  and the interest rate smoothing coefficient  $\rho$ . The response to the output gap is one ( $\gamma = 1$ ). For each specification of the inflation forecast horizon (0, 4, 8, 12, 16 and 20 quarters), multiple equilibria occur for all combinations of the parameters  $\alpha$  and  $\rho$  that lie outside of the shaded area.

IMF-model and the FRB/US model are based on economic theory, they are not rigorously derived from microeconomic optimization problems and thus the concept of a utility function is used only implicitly.<sup>40</sup>

We use numerical methods to compute optimal policy response coefficients and forecast horizons that minimize the weighted average of inflation and output gap variability, subject to an upper bound on interest rate variability. Only rules that yield determinacy are considered in the optimization.

We consider forecast horizons up to 20 quarters and restrict the policy parameters  $\rho$ ,  $\beta$  and  $\gamma$  to the interval  $[0, 3]$ . The latter restriction is sometimes needed to avoid unreasonably high values for the inflation response coefficient (we found values above 100) that do not reduce the value of the loss function significantly more than an inflation response coefficient around three. Furthermore, we

<sup>40</sup>Furthermore, a utility based welfare-function can be extremely model specific. Paez-Farrell (2010) shows that different theories of inflation persistence can result in an observationally equivalent Phillips curve, but imply different loss functions and lead to different policy prescriptions. Therefore, optimal simple rules based on structural loss functions are not robust to model uncertainty.

restrict the analysis to rules that imply a volatility of the first difference of the interest rate that is no greater than the value observed for the U.S. between 1983 and 2007.

**Table 10** provides an overview of the characteristics and performance of optimized rules. For a range of values of  $\lambda$ , the weight on output gap variability in the loss function, the table reports the optimal horizons of inflation and output gap forecasts,  $h_\pi$  and  $h_y$ , and the optimal response coefficients on the lagged interest rate, inflation and the output gap,  $\rho$ ,  $\beta$  and  $\gamma$ . The last column denoted by  $\% \Delta L$  indicates the percentage reduction in the value of the loss function under the optimal forecast-based rule relative to an optimized outcome-based rule. The value is always non-positive because the class of outcome-based rules ( $h_\pi = 0$  and  $h_y = 0$ ) is nested within the class of forecast-based rules. In the cases where the optimal forecast horizon is zero the value of  $\% \Delta L$  is zero.

Table 10: Characteristics and Performance of Optimized Rules

Model	$\lambda$	$h_\pi$	$h_y$	$\rho$	$\beta$	$\gamma$	$\% \Delta L$
CCTW-SW (reestimated)	0	0	20	0.87	3.00	0.00	-2.36
	1/3	0	0	1.00	3.00	0.10	0.00
	1	1	0	1.00	3.00	0.23	-0.06
	3	3	0	0.99	3.00	0.59	-0.33
IMF Model (reestimated)	0	0	2	0.79	3.00	0.31	-13.71
	1/3	1	3	0.82	2.60	3.00	-11.10
	1	1	4	0.77	3.00	2.99	-30.77
FRB/US (linearized, 2003)	3	4	4	0.68	2.88	3.00	-30.92
	0	0	0	0.94	3.00	0.42	0.00
	1/3	18	0	0.97	3.00	2.16	-3.78
	1	18	0	0.97	3.00	2.97	-14.04
	3	16	0	0.98	3.00	3.00	-11.67

Notes: For each model and each value of the preference parameter  $\lambda$ , the table indicates the optimal forecast horizons for inflation and the output gap ( $h_\pi$  and  $h_y$ , respectively) and the optimal values of the policy coefficients  $\rho$ ,  $\beta$  and  $\gamma$ . The table also indicate the percent change in the loss function ( $\% \Delta L$ ) of the optimized rule compared to an optimal outcome-based rule. The interest rate rule is given by:  $i_t = \rho i_{t-1} + (1 - \rho)[i^* + \beta(E_t \pi_{t+h_\pi} - \pi^*) + \gamma E_t y_{t+h_y}]$ . The parameters  $\rho$ ,  $\beta$  and  $\gamma$  are restricted to lie in the interval  $[0,3]$ .

The optimal forecast horizons are mostly below four quarters. One exception is the horizon of the output gap forecast in the CCTW-SW model when the policy maker places no weight on output stabilization ( $\lambda = 0$ ). Other exceptions arise in the FRB/US model, where the inflation forecast horizon can be rather high at 4 to 5 years. Even so, the reported loss function values indicate that responding to forecasts rather than outcomes does not yield major improvements in the stabilization of inflation and the output gap. This finding confirms Levin et al. (2003). The only model where basing policy on forecasts yields sizeable improvements is the IMF's model. The reason is probably the very high degree of inflation and output persistence in this model. In sum, forecast-based rules offer little advantage over outcome-based rules in the majority of the models.<sup>41</sup>

<sup>41</sup>This result is also consistent with Levin et al. (1999) who find that complicated outcome-based rules, which include a

The optimal inflation response coefficient is often near or at the upper corner of the interval considered in the optimization, that is a value of 3.0. The response to the output gap increases with an increasing weight on output stabilization. It remains relatively low in the CCTW-SW model. In the IMF and FRB/US models a positive response coefficient on the output is optimal even if the policy maker places no weight on the stabilization of the output gap ( $\lambda = 0$ ), probably because it is an indicator of future inflation. The optimal interest rate smoothing coefficient is close to unity.

Our findings do not support the conventional wisdom that central bank interest rates need to be set in response to forecasts rather than recent outcomes, because these rates influence output and inflation, i.e. the ultimate target variables, with a lag.<sup>42</sup> It would be useful to extend our analysis by including alternative assumptions regarding the expectations formation of market participants relative to rational expectations. Models with least-squares learning are available, for example, from Slobodyan and Wouters (2009a,b).

## 6.2 Robustness under model uncertainty

The heterogeneity of model-based forecasts documented in the preceding section underscores the great extent of model uncertainty faced by monetary and fiscal policy makers. Thus, even if certain rules perform very well in a given model, the question remains whether they are robust to such model uncertainty. We evaluate the robustness of the type of interest rate rules derived in the preceding subsection by checking how they perform in competing models. In other words, we simulate a situation where the central bank can only use a simplified model that is an imperfect representation of the "true" world. The policy maker searches for an optimal rule in this misspecified model. The evaluation model represents the "true model of the economy", while the model used for the optimization of the policy parameters represents the "misspecified" model.

We conduct this exercise for outcome-based and forecast-based rules to find out which type of rules is more robust to model uncertainty. The exercise is similar to Levin et al. (2003) and Taylor and Wieland (2011). They evaluate the robustness of model-specific rules, respectively, across five and four models. Levin et al. (2003) find that rules that respond to a short horizon inflation forecast of up to one-year ahead and the current output gap and include a high degree of interest rate smoothing are relatively robust to model uncertainty. Rules with longer forecast horizons are less robust in the sense that they lead to indeterminacy in a number of cases. Taylor and Wieland (2011) show that rules that are derived by averaging over the losses incurred in different models are generally more robust than model-specific rules.

First, we consider the robustness of outcome-based rules. **Table 11** reports their performance across the three models. The first column contains the weight on output variability in the loss function

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large number of state variables and are thus similar to information encompassing forecast-based rules, yield only moderate stabilization gains over simple rules.

<sup>42</sup>Of course, this finding does not necessarily preclude the use of forecasts in communications to the public as practiced at many inflation targeting central banks even when central bank's decisions are driven by recent outcomes rather than forecasts of key macroeconomic variables.

Table 11: Robustness of outcome-based model-specific rules

$\lambda$	Model used to optimize the rule	$\rho$	$\beta$	$\gamma$	$Loss$	$\% \Delta L$
evaluated in the CCTW-SW model						
0	IMF	0.79	2.23	1.73	46.79	6346.9
0	FRB	0.96	3.00	0.76	5.53	661.85
1/3	IMF	0.86	3.00	2.63	50.17	274.35
1/3	FRB	0.98	2.99	2.99	46.09	243.91
1	IMF	0.83	2.09	2.82	130.57	283.44
1	FRB	0.97	3.00	1.99	46.90	37.73
evaluated in IMF model						
0	CCTW-SW	0.87	3.00	0.00	1.18	18.97
0	FRB	0.96	3.00	0.76	1.61	59.28
1/3	CCTW-SW	0.99	3.00	0.22	3.11	161.34
1/3	FRB	0.98	2.99	2.99	2.14	179.83
1	CCTW-SW	0.99	3.00	0.53	4.03	137.06
1	FRB	0.97	3.00	1.99	2.80	64.71
evaluated in FRB/US model						
0	CCTW-SW	0.87	3.00	0.00	5.62	80.13*
0	IMF	0.79	2.23	1.73	24.02	669.87*
1/3	CCTW-SW	0.99	3.00	0.22	91.82	239.69
1/3	IMF	0.86	3.00	2.63	26.39	-2.36*
1	CCTW-SW	0.99	3.00	0.53	216.89	217.08
1	IMF	0.83	2.09	2.82	62.97	-7.93*

\*this rule violates the volatility restriction of the interest rate in the model that is used to evaluate the performance of the rule.

Notes: For each model and each value of the preference parameter  $\lambda$ , the table indicates the optimal policy parameters for inflation and output gap outcomes ( $h_\pi = 0$  and  $h_y = 0$ ). The table also indicates the loss and the percent change in the loss function ( $\% \Delta L$ ) of a rule that has been optimized in another model compared to the rule that has been optimized in the same model that is used for the evaluation. A value of  $\infty$  shows that this specific rule does not yield determinacy. The interest rate rule is given by:  $i_t = \rho i_{t-1} + (1 - \rho)[i^* + \beta(E_t \pi_{t+h_\pi} - \pi^*) + \gamma E_t y_{t+h_y}]$ . The parameters  $\rho$ ,  $\beta$  and  $\gamma$  are restricted to lie in the interval [0,3]. We only consider rules that lead to a volatility of the first difference of the interest rate that is equal or lower to what can be empirically observed for the period 1983-2010.

and the second column the name of the optimization model. The next three columns show the policy parameters of the rule to be evaluated. The last two columns indicate the loss and the percentage change in the loss function compared to a rule that has been optimized in the model that is used for the evaluation.

Most optimized rules exhibit a high degree of interest rate smoothing and an inflation coefficient close to the upper bound of 3. The rules differ a lot with respect to the parameter on the output gap. It is rather small in the CCTW-SW model. In the FRB/US model it rises to a value near 3.0 only when output and inflation variability receive equal weight in the loss function. In the IMF model, however, it mostly takes on values between 2 and 3. These differences in the policy parameters lead in most cases to the result that the optimized rule is not robust across the other two models. For example, taking the rule optimized for the Smets & Wouters model with  $\lambda = 1/3$  yields a relative loss of 161.34% in the IMF model and a relative loss of 239.69% in the FRB/US model.<sup>43</sup> Based on

<sup>43</sup>In few cases the rules optimized in another model yield a slight improvement compared to the rule optimized in the



these results policymakers would probably be reluctant to rely on any rule that has been optimized in a single model only.

Table 12: Robustness of model-specific rules with forecast horizon of 3 quarters

$\lambda$	model used to optimize rule	$\rho$	$\beta$	$\gamma$	Loss	$\% \Delta L$
evaluated in CCTW-SW model						
0	IMF	0.65	3.00	0.74	6.87	509.38*
0	FRB	0.95	3.00	0.51	3.95	248.70
1/3	IMF	0.77	3.00	1.81	34.25	155.77*
1/3	FRB	0.94	2.99	0.24	13.75	2.61
1	IMF	0.78	3.00	3.00	78.88	129.17*
1	FRB	0.98	2.85	3.00	69.02	100.50
evaluated in IMF model						
0	CCTW-SW	0.93	3.00	0.00	1.57	40.92
0	FRB	0.95	3.00	0.51	1.66	48.26
1/3	CCTW-SW	0.78	3.00	0.04	1.39	13.77
1/3	FRB	0.94	2.99	0.24	1.94	58.87
1	CCTW-SW	0.99	3.00	0.43	3.63	111.57
1	FRB	0.98	2.85	3.00	2.95	71.73
evaluated in FRB/US model						
0	CCTW-SW	0.93	3.00	0.00	6.93	56.94
0	IMF	0.65	3.00	0.74	$\infty$	$\infty$
1/3	CCTW-SW	0.78	3.00	0.04	$\infty$	$\infty$
1/3	IMF	0.77	3.00	1.81	24.80	-65.63*
1	CCTW-SW	0.99	3.00	0.43	261.28	135.91
1	IMF	0.78	3.00	3.00	77.70	-29.84*

\*this rule violates the volatility restriction of the interest rate in the model that is used to evaluate the performance of the rule.

Notes: The parameters are optimized for an inflation forecast horizon and an output gap horizon of three quarters ahead ( $h_\pi = 3$  and  $h_y = 3$ , respectively). A value of  $\infty$  shows that this specific rule does not yield determinacy.

**Table 12** reports the performance and robustness of forecast-based rules. We choose a forecast horizon of three quarters for inflation and the output gap as in the empirical estimation of forecast-based policy rules for the U.S. in section 4.

Our findings indicate that model-specific rules are not robust to model uncertainty as suggested by Taylor and Wieland (2011), Model-specific rules are fine-tuned to a particular model and imply a substantial increase in loss in other models.

Rules responding to forecasts are even less robust than the outcome-based rules in the sense that they lead to indeterminacy in two cases. If we increase the forecast horizon to 7 quarters equilibrium indeterminacy arises more frequently (not shown). For example, the rules optimized in the IMF model then always induce indeterminacy in the other two models.

In sum, we find that the advantages of forecast-based policy rules in terms of incorporating information on a wide range of state variables via the forecasts do not translate to important gains in stabilization performance. By contrast, forecast-based rules are more prone to generate equilibrium evaluation model, but violate the imposed upper bound of the interest rate volatility. These rules are thus not desirable.

indeterminacy. Rules that respond to longer-horizon forecasts perform worse across models. An important extension of this analysis would be to consider the performance of model-averaging rules as proposed by Taylor and Wieland (2011).

## 7 Outlook

This chapter has been concerned with studying the link between economic forecasts and policy making, focussing in particular on the areas of monetary and fiscal policy. Having presented a simple framework for linking forecasts with policy decisions, we then provided evidence that central bank interest rate decisions are well explained by a reaction to central bank forecasts. While there is a large literature on central bank reaction functions, it would be of great interest to shed more light on the relationship between fiscal forecasts and policy decisions. There is evidence that asymmetries may play an important role in explaining budgetary forecasts. Such asymmetric costs are likely to play an increasingly important role in the euro area as supra-national efforts for exerting greater fiscal discipline on the national level take hold. An effective implementation of such fiscal discipline would require careful monitoring of the quality of fiscal forecasts.

A large part of this chapter has then been devoted to the study of structural models that can be used to compute forecasts that account for the interaction with policy decisions. We have also documented that model-based forecasts just like expert forecasts have missed the onset of the great recession in 2008/2009. In fact, models and experts generally have difficulty predicting recessions. On the positive side, models and experts provided reasonably useful forecasts of the recovery process. Using a small projection model from the IMF we found that information drawn from bank lending surveys helped explain the recent recession as a consequence of the global financial crisis. However, the bank lending information appeared not sufficiently predictable to improve the forecasting performance of the model. Of related interest is the evaluation of the forecasting performance of DSGE models with financial factors in the chapter on DSGE forecasting in this handbook by Del Negro and Schorfheide (2012). In this chapter we used a medium-size DSGE model with a fiscal sector to explore the use of alternative conditioning assumptions in predicting the GDP impact of the 2009 U.S. fiscal stimulus package. Our estimates indicate a fairly small stimulative effect of such measures.

Going forward, it is of eminent importance to develop the financial sector of DSGE models to better capture the experience of credit boom followed by credit bust that led to the global financial crisis and to integrate more realistic structural representations of the fragilities in financial intermediation. Hopefully, such modeling improvements will not only help explain past developments but also improve forecasting accuracy.

The diversity of model and expert forecasts suggests that forecast heterogeneity and learning dynamics might play an important role in propagating economic fluctuations. The structural forecasting models considered in this chapter, however, all rely on the assumption of homogenous and rational expectations. It is urgent to integrate heterogeneous expectations and learning in structural models and evaluate the forecasting performance of such models.

Furthermore, much work remains to be done in integrating the process in which policy makers learn from the data and revise their models of the economy formally in policy design.

Finally, the closing section on robustness of forecast-based policies under model uncertainty introduces a cautionary note. While forecasts play an important role in many economic policy decision making processes caution should be exerted in basing policy explicitly on longer-run forecasts. Model uncertainty is a major practical problem. Research on Bayesian model averaging, robust control and worst-case analysis may help support more effective policy design that is robust to model uncertainty.

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## A A medium-scale DSGE model

This appendix provides a description of the Smets & Wouters model with rule-of-thumb consumers estimated in Cogan et al. (2010).

The resource constraint is given by:

$$y_t = c_y c_t + i_y i_t + z_y z_t + g_t, \quad (27)$$

where output  $y_t$  is the sum of consumption,  $c_t$ , and investment,  $i_t$ , weighted with their steady state ratios to output ( $c_y$  and  $i_y$ ), the capital-utilization cost which depends on the capital utilization rate,  $z_t$ , and government spending  $g_t$ .  $g_t$  follows an AR(1) process and is also affected by the technology shock.  $z_y$  equals  $R_*^k k_y$ , where  $k_y$  is the ratio of capital to output in steady state and  $R_*^k$  is the rental rate of capital in steady state.

A share  $1-\omega$  of households indexed by  $j \in [0, 1-\omega)$  makes optimizing, forward looking decisions and these households have access to financial markets. The remaining share  $\omega$  of households indexed by  $i \in [1-\omega, 1]$  - the rule-of-thumb consumers - do not have access to financial markets and simply consume their wage income less lump-sum tax payments:

$$c_{i,t} = W_*^h L_* / C_*(w_t + L_t) - c_y^{-1} t_t, \quad (28)$$

where parameters with a \* subscript denote steady state values. Combining the optimizing households' first order conditions for consumption and bond holdings yields the same consumption Euler equation as in Smets and Wouters (2007). Labor unions set the same nominal wage rate for both types of households. Hence, labor supply is equalized across the two groups. The consumption Euler equation for optimizing households is thus given by:

$$c_{j,t} = c_1 c_{j,t-1} + (1 - c_1) E_t(c_{j,t+1}) + c_2 (l_t - E_t(l_{t+1})) - c_3 (r_t - E_t(\pi_{t+1})) + \epsilon_t^b. \quad (29)$$

The parameters are  $c_1 = (\lambda/\gamma)/(1 + \lambda/\gamma)$ ,  $c_2 = [(\sigma_c - 1)(W_*^h L_*/C_*)]/[(\sigma_c(1 + \lambda/\gamma))]$  and  $c_3 = (1 - \lambda/\gamma)/[(1 + \lambda/\gamma)\sigma_c]$ .  $\lambda$  governs the degree of habit formation,  $\gamma$  is the labor augmented steady growth rate,  $\sigma_c$  the inverse of the intertemporal elasticity of substitution.  $\epsilon_t^b$  denotes an AR(1) shock process on the premium over the central bank controlled interest rate. Consumption of optimizing households is a weighted average of past and expected consumption due to habit formation. The consumption Euler equation depends on hours worked,  $l_t$ , because of the non-separability of utility. When consumption and hours are complements ( $\sigma_c > 1$ ), consumption of optimizing households increases with current hours and decreases with expected hours next period. The real interest rate and the shock term affect aggregate demand by inducing intertemporal substitution in consumption. Overall consumption is a weighted average of consumption of both types of households:

$$c_t = (1 - \omega)c_{j,t} + \omega c_{i_t}. \quad (30)$$

The investment Euler equation is given by

$$i_t = i_1 i_{t-1} + (1 - i_1)E_t(i_{t+1}) + i_2 q_t + \epsilon_t^i, \quad (31)$$

where  $i_1 = 1/(1 + \beta\gamma^{1-\sigma_c})$  and  $i_2 = [1/(1 + \beta\gamma^{1-\sigma_c})\gamma^2\phi]$ .  $\beta$  denotes the discount factor,  $\phi$  the elasticity of the capital adjustment cost function,  $q_t$  Tobin's Q and  $\epsilon_t^i$  an investment specific technology shock that follows an AR(1) process. Current investment is a weighted average of past and expected future investment due to the existence of capital adjustment costs. It is positively related to the real value of the existing capital stock. This dependence decreases with the elasticity of the capital adjustment cost function. The arbitrage equation for the real value of the capital stock is:

$$q_t = q_1 E_t(q_{t+1}) + (1 - q_1)E_t(r_{t+1}^k) - (r_t - E_t(\pi_{t+1}) + \epsilon_t^b), \quad (32)$$

where  $q_1 = \beta\gamma^{-\sigma_c}(1 - \delta)$ .  $r_t^k$  denotes the real rental rate of capital and  $\delta$  the depreciation rate of capital. The real value of the existing capital stock is a positive function of its expected value next period and the rental rate on capital and a negative function of the real interest rate and the external finance premium.

The production process is assumed to be determined by a Cobb-Douglas production function with fixed costs:

$$y_t = \phi_p(\alpha k_t^s + (1 - \alpha)l_t + \epsilon_t^a). \quad (33)$$

$k_t^s$  denotes effective capital (physical capital adjusted for the capital utilization rate),  $\epsilon_t^a$  a neutral productivity shock that follows an AR(1) process and  $\phi_p$  is one plus the share of fixed costs in production. Output is produced using capital and labor and is boosted by technology shocks. Capital used in production depends on the capital utilization rate and the physical capital stock of the previous period as new capital becomes effective with a lag of one quarter:

$$k_t^s = k_{t-1} + z_t. \quad (34)$$

Household income from renting capital services to firms depends on  $r_t^k$  and changing capital utilization is costly so that the capital utilization rate depends positively on the rental rate of capital:

$$z_t = (1 - \psi)/\psi r_t^k, \quad (35)$$

where  $\psi \in [0, 1]$  is a positive function of the elasticity of the capital utilization adjustment cost function. The law of motion for physical capital is given by:

$$k_t = k_1 k_{t-1} + (1 - k_1) i_t + k_2 \epsilon_t^i, \quad (36)$$

where  $k_1 = (1 - \delta)/\gamma$  and  $k_2 = (1 - (1 - \delta)/\gamma)(1 + \beta\gamma^{1-\sigma_c})\gamma^2\phi$ . The price mark-up  $\mu_t^p$  equals the difference between the marginal product of labor and the real wage  $w_t$ :

$$\mu_t^p = \alpha(k_t^s - l_t) + \epsilon_t^a - w_t. \quad (37)$$

Monopolistic competition, Calvo-style price contracts, and indexation of prices that are not free to be chosen optimally combine to yield the following Phillips curve:

$$\pi_t = \pi_1 \pi_{t-1} + \pi_2 \pi_{t+1} - \pi_3 \mu_t^p + \epsilon_t^p, \quad (38)$$

with  $\pi_1 = \iota_p/(1 + \beta\gamma^{1-\sigma_c}\iota_p)$ ,  $\pi_2 = \beta\gamma^{1-\sigma_c}/(1 + \beta\gamma^{1-\sigma_c}\iota_p)$ , and  $\pi_3 = 1/(1 + \beta\gamma^{1-\sigma_c}\iota_p)[(1 - \beta\gamma^{1-\sigma_c}\xi_p)(1 - \xi_p)/\xi_p((\phi_p - 1)\epsilon_p + 1)]$ . This Phillips curve contains not only a forward-looking but also a backward-looking inflation term because of price indexation. Firms that cannot adjust prices optimally either index their price to the lagged inflation rate or to the steady-state inflation rate. Note, this indexation assumption ensures also that the long-run Phillips curve is vertical.  $\xi_p$  denotes the Calvo parameter,  $\iota_p$  governs the degree of backward indexation,  $\epsilon_p$  determines the curvature of the Kimball (1995) aggregator. The Kimball aggregator complementarity effects enhance the price rigidity resulting from Calvo-style contracts. The mark-up shock  $\epsilon_t^p$  follows an ARMA(1,1) process. A monopolistic labor market yields the condition that the wage mark-up  $\mu_t^w$  equals the real wage minus the marginal rate of substitution  $mrst_t$ :

$$\mu_t^w = w_t - mrst_t = w_t - (\sigma_l l_t + \frac{1}{1 - \lambda/\gamma}(c_t - \lambda/\gamma c_{t-1})), \quad (39)$$

with  $\sigma_l$  being the Frisch elasticity of labor supply. The wage Phillips curve is given by:

$$w_t = w_1 w_{t-1} + (1 - w_1)(E_t(w_{t+1}) + E_t(\pi_{t+1})) - w_2 \pi_t + w_3 \pi_{t-1} - w_4 \mu_t^w + \epsilon_t^w, \quad (40)$$

where  $w_1 = 1/(1 + \beta\gamma^{1-\sigma_c})$ ,  $w_2 = (1 + \beta\gamma^{1-\sigma_c}\iota_w)/((1 + \beta\gamma^{1-\sigma_c}))$ ,  $w_3 = \iota_w/(1 + \beta\gamma^{1-\sigma_c})$ , and  $w_4 = 1/(1 + \beta\gamma^{1-\sigma_c})[(1 - \beta\gamma^{1-\sigma_c}\xi_w)(1 - \xi_w)/(\xi_w((\phi_w - 1)\epsilon_w + 1))]$ . The parameter definition is analogous to the price Phillips curve.

Setting  $\xi_p = 0$ ,  $\xi_w = 0$ ,  $\epsilon_t^p = 0$  and  $\epsilon_t^w = 0$  one obtains the efficient flexible price and flexible wage allocation. The output gap  $x_t$  is defined as the log difference between output and flexible price output just like in the small-scale New-Keynesian models above.

The government purchases consumption goods  $g_t$ , issues bonds  $b_t$  and raises lump-sum taxes  $t_t$ . The government budget constraint is then given by:

$$b_t = R_* (b_{t-1} \pi_*^{-1} + g_t - t_t), \quad (41)$$

where  $R_*$  denotes the nominal steady state interest rate and  $\pi_*$  the steady state inflation rate. Fiscal policy follows a rule suggested by Galí et al. (2007):

$$t_t = \phi_b b_t + \phi_g g_t, \quad (42)$$

where  $\phi_b$  and  $\phi_g$  determine the elasticities of lump-sum taxes with respect to government debt and government spending.

The monetary policy rule reacts to inflation, the output gap and the change in the output gap and incorporates partial adjustment:

$$r_t = \rho r_{t-1} + (1 - \rho)(r_\pi \pi_t + r_x x_t) + r_{\Delta x_t} (x_t - x_{t-1}) + \epsilon_t^r. \quad (43)$$

$\epsilon_t^r$  is a monetary policy shock that follows an AR(1) process.

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